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Simulation of Real-Gas Effects on Pressure Distributions for Aeroassist Flight Experiment Vehicle and Comparison With Prediction

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Summary

The Aeroassist Flight Experiment (AFE) utilizes a 14-ft-diameter raked and blunted elliptic cone as a vehicle to carry instrumentation for 10 experiments on a Shuttle-launched flight. The flight is to obtain aerodynamic and aerothermodynamic data for blunt bodies with velocities near 32 000 fps at altitudes above approximately 245 000 ft. A preflight ground-based test program was initiated to provide calibration data for computational fluid dynamics (CFD) codes that will be used in flight predictions. The present data are results from a portion of that test program.

Pressure distributions measured on a 60° half-angle elliptic cone, raked off at an angle of 73° to the cone centerline and having an ellipsoid nose (ellipticity equal to 2.0 in the symmetry plane), are presented for angles of attack from −10° to 10°. The effects of normal shock density ratio (a real-gas simulation parameter) and Reynolds number on pressure distributions for the AFE configuration are examined. The high normal shock density ratio aspect of a real gas was simulated on measured pressure distributions by testing at Mach 6 in ideal air (density ratio equal to 5.25) and in CF_4 (density ratio equal to 12.0). Reynolds number per foot was varied in air from 0.60×10^6 to 2.2×10^6. Pressure distributions predicted with modified Newtonian theory and a three-dimensional Euler code known as HALIS were compared with measurements for angles of attack of 0°, −10°, and 10°.

A significant effect of normal shock density ratio on pressure distributions in the nose-cone expansion region was observed. That is, typical of real-gas effects, the magnitude of the surface pressure in regions of compression such as the nose is relatively unaffected by an increase in density ratio; however, in regions of expansion such as those that occur as the flow moves off the nose onto the conical section, the pressure decreases because of an increase in density ratio. The magnitude of this effect decreased with increasing angle of attack (effective bluntness) for the range covered in these tests. The effect of Reynolds number on pressure distributions in air was negligible for forebody pressure distributions, but a measurable effect was noted on base pressures. Pressure distributions predicted with HALIS were in good agreement with measurement, whereas those predicted with modified Newtonian theory were in poor agreement over the cone section for air but in better agreement for CF_4 over the range of angle of attack.

Introduction

The transfer of cargo and personnel from low to high (e.g., geosynchronous) Earth orbit will be an important phase of future space transportation operations. Special vehicles, formerly referred to as orbital transfer vehicles (OTV's) but more recently referred to as space transfer vehicles (STV's), will perform this task. Upon return of the vehicle from high Earth orbit, its velocity must be greatly reduced in order to achieve a near circular low Earth orbit. This decrease in velocity can be achieved either by use of retro-rockets or by guiding the vehicle through a portion of the Earth's atmosphere and allowing aerodynamic drag forces to act on the vehicle. A number of studies have indicated that lower propellant loads are required, and therefore payloads can be increased, for the aeroassist method. (See refs. 1 and 2.) Vehicles being considered for the aeroassist method, generally referred to as aeroassisted space transfer vehicles (ASTV's), will have a high drag and thus a relatively low lift-drag ratio (L/D) and will fly at very high altitudes and velocities throughout the atmospheric portion of the trajectory. Because of the high altitude, high velocity trajectory, flight experience is scarce and ground-based facilities are, in general, not capable of the simulation of the flow environment.

The proposed trajectory for an ASTV is quite different than that of the Apollo spacecraft or Space Shuttle orbiter. Also, ground-based facilities are not well suited to duplicating the high Mach number and low Reynolds number speed regime in which ASTV's fly. Thus, an experimental ASTV flight has been proposed for the purpose of obtaining aerodynamic and aerothermodynamic data for blunt bodies with velocities near 32 000 fps and at altitudes above approximately 245 000 ft. The experimental ASTV is referred to as the Aeroassist Flight Experiment (AFE). A comprehensive discussion of the rationale for this flight experiment is presented in reference 3, and the experiments to be performed are described in reference 4. The AFE vehicle is derived from a blunted 60° half-angle elliptic cone that is raked off at 73° to the centerline. This rake angle produces a circular rake plane to which a skirt is added to reduce heating around the base periphery. The vehicle will be transported in the payload bay of the Space Shuttle orbiter and launched from the Shuttle into low Earth orbit. An onboard rocket motor will then be fired which will propel the vehicle into the atmosphere to simulate the velocity and trajectory of a return mission from geosynchronous orbit. Onboard instrumentation will measure and record the aerodynamic characteristics and aerothermodynamic environment of this entry trajectory, and the data will be used to validate computational fluid dynamics (CFD) computer codes and ground-to-flight extrapolations of experimental data for use in future ASTV designs. The aerodynamic/aerothermodynamic design of the AFE vehicle, however, must rely on experimental wind tunnel data and predictions from CFD codes that are currently in existence or being developed. These codes must be calibrated with the best available data from ground-based facilities and then applied to predict the flight environment.

Since the trajectory of the AFE includes flow regimes ranging from continuum to free molecular flow, a substantial portion of this trajectory will carry the vehicle through conditions resulting in chemical and thermal nonequilibrium within the surrounding shock layer. Also, chemical nonequilibrium effects may be important well into the continuum range. (See, for example, refs. 5 and 6.) Although most of the AFE flight environment cannot be adequately simulated in ground-based facilities, these facilities contribute substantially to the understanding of certain aspects of the flight environment and provide a valuable point for the calibration of CFD codes. For example, real-gas effects in high velocity flight are the result of excitation of vibration, dissociation, and ionization energy modes of the atmospheric gas as it passes through the bow shock of the vehicle. As dissociation is initiated and driven toward completion, the density ratio across the normal portion of the bow shock increases to values two to three times those obtained in conventional-type, hypersonic air or nitrogen wind tunnels. For blunt bodies at hypersonic speeds, the primary factor governing the shock standoff distance and inviscid forebody flow is the normal shock density ratio. (See refs. 7, 8, and 9.) Therefore, certain aspects of a real gas in thermochemical nonequilibrium can be simulated by the selection of a test gas having a low ratio of specific heats which provides large values of density ratio. These conditions can be obtained in the Langley Hypersonic CF_4 Tunnel at Mach 6. This tunnel, in conjunction with the Langley 20-Inch Mach 6 Tunnel, provides the capability to test a given model at the same free-stream Mach number and Reynolds number but at two values of density ratio (5.25 in air and 12.0 in CF_4); this value of density ratio for CF_4 is closer to the maximum value expected in flight, which is about 16–18.

A set of high-fidelity AFE configuration models was designed, constructed, and tested at the Langley Research Center to obtain both aerodynamic and aerothermodynamic data over a wide range of conditions as discussed in reference 10. Results from experimental studies performed on this configuration are presented in references 11, 12, and 13. Also, CFD codes were applied to the proposed configuration and include the prediction of forces and moments, surface pressure distributions, and heating distributions. (See refs. 5, 6, and 11 through 18.) The purpose of this paper is twofold: (1) to present data illustrating the effect of density ratio on pressure distributions over a range of angle of attack for the AFE and (2) to compare these experimental test results with those predicted by an inviscid flow-field code referred to as HALIS (ref. 14). These experimental data and comparisons with predictions are expected to be of significant interest to the designers of the AFE aeroshell and to the principal investigators of the various onboard experiments.

Symbols

C_m	pitching-moment coefficient
C_p	pressure coefficient, $\frac{p - p_\infty}{q_\infty}$
$C_{p,\mathrm{ref}}$	reference pressure coefficient, $\frac{p_{t,2} - p_\infty}{q_\infty}$
L	model base length in symmetry plane, in. (see fig. 2)
M	Mach number
p	pressure, psi
q	dynamic pressure, psi
Re	unit Reynolds number per foot
r	radius, in.
s	wetted surface length from geometric stagnation point, in. (see fig. 5(b))
T	temperature, °R
U	velocity, fps
y, z	vertical and axial coordinates for AFE (see fig. 5)
α	angle of attack, deg
γ	ratio of specific heats
ρ	density, lbm/ft^3
Φ	ray angle from geometric stagnation point, deg (see fig. 2)

Subscripts:

b	base
ref	reference

$t,1$	reservoir conditions
$t,2$	stagnation conditions behind normal shock
2	static conditions behind normal shock
∞	free-stream static conditions

Abbreviations:

AFE	Aeroassist Flight Experiment
CF_4	tetrafluoromethane
ESP	electronically scanned pressure
VDC	volts direct current

Apparatus and Tests

Facilities

Langley Hypersonic CF_4 Tunnel. The Langley Hypersonic CF_4 Tunnel is a blowdown wind tunnel that uses tetrafluoromethane (CF_4), which has a relatively low (in comparison to air) ratio of specific heats, as the test gas. The CF_4 is heated to a maximum temperature of 1530°R by two lead bath heaters connected in parallel. The maximum reservoir pressure is 2500 psia. Flow is expanded through an axisymmetric, contoured nozzle designed to generate a Mach number of 6 at the 20-in-diameter exit; this facility has an open-jet test section. A detailed description of the CF_4 Tunnel, along with calibration results, is presented in reference 19.

Langley 20-Inch Mach 6 Tunnel. The Langley 20-Inch Mach 6 Tunnel is also a blowdown wind tunnel but uses dry air as the test gas. The air is heated to a maximum temperature of 1088°R by an electrical resistance heater, and the maximum reservoir pressure is 525 psia. A fixed geometry, two-dimensional, contoured nozzle with parallel sidewalls expands the flow to Mach 6 at the 20-in. square test section. A description of this facility and the calibration results are presented in reference 20.

Model

A photograph and a sketch of the 0.022-scale (3.67-in. symmetry plane base length) pressure model are shown in figure 1. The AFE vehicle shape is derived from a 60° half-angle elliptic cone that is raked off at 73° to the centerline, producing a circular rake plane. The cone is blunted with an ellipsoid nose (ellipticity equal to 2.0 in the symmetry plane) which is tangent to the cone at all points of their intersection. A skirt, having an arc radius equal to one tenth the diameter of the rake plane and an arc length corresponding to 60°, has been attached to the rake plane in order to reduce heating in the corner region. The circular arc is tangent to the cone in all meridional planes. A detailed description of the analytical shape of the configuration is presented in reference 21.

Two AFE pressure models were machined from stainless steel, each with a wall thickness of 0.20 in. The first has 67 windward surface pressure orifices with two additional orifices located on the flat base (fig. 2). During fabrication and tubing of the first model, a number of particularly important orifice tubes were found to leak and could not be repaired because of the close proximity of the tubes. Thus, a second model was fabricated to include those orifices and, in order to add credibility to the data, repeat a number of other orifices on the first model. Pressure orifices are distributed along seven rays emanating from the geometric stagnation point, as shown in figure 2, and are 0.040 in. in diameter. Two base pressure orifices are located along the 0° and 180° rays on the base ($\frac{r}{L/2} = 0.782$) and are 0.060 in. in diameter. Models were sting mounted with a sting-to-base area ratio of 0.074; the constant diameter sting extended 12 in. beyond the base plane. This model mounting arrangement was used in all facilities. Both models were cut on a numerical milling machine from a tape generated with the geometry program described in reference 21. Since this geometry is also used to generate the geometry in the HALIS code (discussed subsequently), differences between the experimental and theoretical model were measured and found to be within a machining tolerance of ± 0.003 in.

Test Conditions

Flow conditions in the Hypersonic CF_4 Tunnel and the 20-Inch Mach 6 Tunnel were determined from the measured reservoir pressure, reservoir temperature, and pitot pressure at the test section as discussed in references 19 and 20. Calculated nominal reservoir and test-section flow conditions for the present study are presented in table I for the two reservoir pressure settings in the 20-Inch Mach 6 Tunnel and for the reservoir pressure setting in the Hypersonic CF_4 Tunnel. These reservoir pressure settings resulted in nominal free-stream Reynolds numbers based on length of 2.05×10^5 and 6.61×10^5 in air and 1.76×10^5 in CF_4.

The angle of attack, defined as the incidence between the flow direction and axis of the 60° half-angle elliptic cone (fig. 1(b)), was varied from $-10°$ to 10° in 5° increments. The yaw angle was zero for all tests.

Instrumentation

Model surface pressures were measured with an electronically scanned pressure (ESP) system in both wind tunnels. Each scanner consists of 32 or 48 silicon piezoresistive pressure transducers mounted to a common substrate. All analog outputs are multiplexed within the sensor and are amplified to provide a full-scale output of ± 5 VDC nominally. A more detailed description of the ESP scanners may be obtained from reference 22. In addition to the ESP system, several variable-capacitance diaphragm transducers were also used. These transducers have seven ranges of pressure with the maximum being 20 psi. In order to provide confidence in the measured results, three model orifices and a tunnel total pressure probe were connected to both the ESP system and to a variable-capacitance diaphragm transducer by use of a tee. This approach was taken since the present study was the first large-scale pressure test with the ESP system in the 20-Inch Mach 6 Tunnel.

Schlieren photographs of the AFE configuration were obtained in Mach 6 air and CF_4. (See fig. 3.)

Data Reduction and Uncertainty

As mentioned previously, both the ESP scanners and the variable-capacitance diaphragm transducers were used to measure pressures simultaneously over several locations on the model. Pressure measurements between the ESP system and the variable-capacitance diaphragm transducers generally agreed to within 0.5 percent; the maximum difference observed was 1.5 percent. Repeatability within a run, for which the first and last points were repeats of one another (i.e., same attitude and flow conditions), indicated that measurements made with the ESP system could be repeated to within 1.0 percent; run-to-run repeatability was within 2.0 percent. Repeatability between pressure measurements made with the two different models at the same orifice locations was within 1–2 percent. Of particular concern in pressure measurements is the time required for the pressure transducers to stabilize at the true value of pressure at the model surface (lag time) for a particular set of test conditions. In the present tests, pressure tube lengths from the orifice to the measuring device were about 5 ft in the 20-Inch Mach 6 Tunnel and 3 ft in the CF_4 Tunnel. The ESP modules were located within an insulated box positioned at the base of the strut assembly. (See fig. 4.) For this arrangement, typical settling times for surface pressures measured on the windward face were within 2.0 sec from the moment of insertion into the flow, whereas base pressures required approximately 5.0 sec to reach a steady-state value. The relatively large volume variable-capacitance diaphragm transducers, however, required longer settling times of approximately 5 to 10 sec to reach a constant value on the windward face.

The tunnel run time was sufficient to obtain constant values of surface pressure for both measuring systems. (Run times in the Hypersonic CF_4 Tunnel and the 20-Inch Mach 6 Tunnel were 15 sec and 2.5 min, respectively.) The uncertainty of the pressure measurements presented herein for the forebody is believed to be less than ± 2.0 percent. The uncertainty in base pressure measurements presented herein is believed to be approximately ± 5 percent.

The measured $p_{t,2}$ from the pitot probe mounted in the 20-Inch Mach 6 Tunnel was generally 2.0 percent less than that measured at the geometric stagnation point ($s/L = 0.0$) of the model at $\alpha = 0°$. For this reason, $C_{p,\mathrm{ref}}$ was adjusted by 2.0 percent so that the ratio of measured local pressure at the geometric stagnation point to the measured stagnation pressure behind a normal shock at $\alpha = 0°$ was set to unity. Following the discussion presented in reference 20, a correlation of $p_{t,2}$ at this condition was established for all other conditions so that $C_{p,\mathrm{ref}}$ inferred from the pitot pressure was adjusted by 2.0 percent for all values of α. The measured $p_{t,2}$ from the pitot probe mounted in the Hypersonic CF_4 Tunnel was within 0.5 percent of the pressure measured at the geometric stagnation point of the model at $\alpha = 0°$. Thus, no adjustment of $C_{p,\mathrm{ref}}$ was made for pressure measurements in CF_4.

The shock detachment distance was read manually from schlieren photographs with the use of a digitizing system. The maximum uncertainty in measured shock detachment distance is believed to be less than 5 percent.

Prediction Method

The method used to predict surface pressure distributions is known as the HALIS (High ALpha Inviscid Solution) Code and is discussed in greater detail in references 14, 15, 23, and 24. HALIS is a time-asymptotic method which solves the time-dependent, three-dimensional, compressible Euler equations and was developed for the CDC® CYBER 205 computer system (ref. 23), which is a vector-processing system. The use of vector processing allows HALIS to compute the flow field over complex three-dimensional bodies with large embedded subsonic regions in approximately 60 to 75 min on the CYBER 205. The geometry over which calculations were made and the wind tunnel model are the same except for the downstream aft corner of the model. As discussed in reference 14, HALIS cannot account for the expansion of flow around the aft portion of the skirt and into the base region. To prevent the onset of computational instabilities due to flow expansion around the skirt, a cylindrical extension was added. This extension lies parallel to the z axis (fig. 5) and is tangent to the aft body; thus, a small portion of the vehicle (primarily on the lower portion of the skirt) is not properly modeled. However, the difference between this "computer code model" and the vehicle geometry has a negligible effect on comparisons between measured and predicted pressure distributions. The basic inputs to HALIS, in terms of flow conditions, were nominal values of M_∞ and γ_∞ for the air tests, since the air behaved ideally. HALIS was modified prior to this study to include the thermodynamic properties of CF_4 (ref. 24); thus, this code was exercised with the thermodynamic relations for CF_4 (ref. 25) as opposed to a Mach number and effective γ. The computational results presented herein were generated by K. James Weilmuenster of the Space Systems Division, Langley Research Center.

Pressure distributions predicted with modified Newtonian theory ($C_{p,\text{max}} = C_{p,\text{ref}}$) are presented herein. Surface deflection angles used in the Newtonian calculations were generated with the body surface derivatives obtained from the geometry code of reference 21.

Results and Discussion

The effects of angle of attack, Reynolds number, and normal shock density ratio on pressure distributions measured on the Aeroassist Flight Experiment configuration, as well as accompanying comparisons with prediction, are presented herein. Measured and predicted pressure distributions are presented in terms of local pressure coefficients normalized by a reference pressure coefficient and plotted as a function of wetted surface length nondimensionalized by the base length in the symmetry plane. These data are presented for the seven rays, namely 0° and 180°, 225°, 250°, 270°, 290°, and 315° as measured in a clockwise fashion from the 0° ray and emanating from the geometric stagnation point. (See fig. 2(a).)

Measured pressure distribution data in air are presented in tables II and III for low and high reservoir pressure conditions (i.e., low and high Reynolds number conditions) in the 20-Inch Mach 6 Tunnel, respectively. Tabulated pressure distribution data measured in the Hypersonic CF_4 Tunnel are presented in table IV.

Effect of Normal Shock Density Ratio on Shock Shapes

The effect of normal shock density ratio on shock shapes is presented for Mach 6 air ($\rho_2/\rho_\infty = 5.25$) and CF_4 ($\rho_2/\rho_\infty = 12.0$) at $\text{Re}_{\infty,L} \approx 2.0 \times 10^5$ in figure 6 for $\alpha = -10°$. When density ratio is increased from 5.25 for air to 12.0 for CF_4, the shock detachment distance decreases as expected (ref. 26). For $\alpha \leq 0°$, an inflection was noted in the shock shape for CF_4 downstream of the nose-cone junction. For air test gas, an inflection in the shock shape was also observed but only for $\alpha = -10°$. This inflection is indicative of a flow overexpansion process (discussed subsequently) and is most pronounced for CF_4 test gas at low angles of attack. The effect of angle of attack on shock shapes in Mach 6 air and CF_4 for the AFE is discussed in greater detail in reference 12.

Effect of Angle of Attack on Pressure Distributions

Measured pressure distributions for the AFE configuration in air and CF_4 are presented in figures 7 and 8 for a range of angle of attack and a nominal Reynolds number of 6.61×10^5 and 1.76×10^5, respectively. The variation of the pressure coefficient ratio $C_p/C_{p,\text{ref}}$ with wetted surface length s/L for the symmetry plane ($\Phi = 0°$ and 180°) is presented in figures 7(a) and 8(a). Along the $\Phi = 0°$ ray, the pressures are well behaved and increase with decreasing α. For the Mach 6 air data, a slight overexpansion of the flow from the ellipsoid nose to the conical surface is observed along the $\Phi = 180°$ ray for $\alpha = -10°$, whereas an inflection in the pressure distribution near the nose-cone junction ($s/L = 0.22$) is noted at $\alpha = -5°$ and 0°. For $\alpha \leq 5°$ in CF_4 test gas (fig. 8(a)), a pronounced overexpansion of the flow from the ellipsoid nose to the conical surface is observed. Also, an inflection at the nose-cone junction is noted for $\alpha = 10°$. This overexpansion and/or inflection is due to the influence of the cone section on the expansion over the nose. For $\alpha > 0°$ and air test gas, the pressure decreases monotonically on the cone section in the direction of the cone corner junction ($s/L = 0.76$). Also noted for the symmetry plane is the characteristic movement of the region of maximum pressure with varying angle of attack. As α is decreased from zero, the stagnation region is relatively well-defined and moves farther up and around the elliptical nose along the $\Phi = 0°$ ray, as expected. However, as α is increased from zero, for the Mach 6 air data, the stagnation region is not as well-defined and takes the appearance of a relatively large constant pressure area centered between the nose

($s/L = 0.0$) and the juncture of the elliptical nose and conical surface ($s/L = 0.22$).

As noted in the experimental distributions, the flow over the nose and cone section is subsonic ($M < 1$) near the surface for all values of α in air; however, for the Mach 6 CF_4 data at $\alpha = -10°$, the flow near the surface overexpands to a sonic ($M = 1$) condition at the ellipsoid nose-cone junction and remains near a sonic condition over the entire cone section. (Note that if the flow within the shock layer expands isentropically from the stagnation region, it will become supersonic when $C_p/C_{p,\mathrm{ref}} < 0.5175$ for air and $C_p/C_{p,\mathrm{ref}} < 0.5658$ for CF_4.) The 20° variation in α presented in figures 7(a) and 8(a) produces a wider variation in pressure ratio on the cone section for CF_4 than air.

As illustrated by flow field calculations in reference 14 and presented for Mach 10 air, the flow field for air (fig. 9(a)) is dominated by subsonic flow near the surface at all angles of attack. However, as the angle of attack is decreased the amount of subsonic flow within the forebody shock layer decreases. Since the subsonic region on the body surface terminates at the skirt, it allows the expansion about the skirt to feed upstream and alter the surface pressure distributions, as observed in figure 7. (These shock shapes and shock layer sonic region comparisons are similar to those for Mach 6 air.) For similar predictions with CF_4 as the test gas (fig. 9(b)), where the normal shock density ratio is much higher than air (11.90 compared with 5.25 for Mach 6) and γ within the shock layer is also much lower (1.12 compared with 1.40), there are significant changes in the flow field. At $\alpha = 10°$, the flow field would be predominantly subsonic like in air; however, as the angle of attack is decreased, the region of subsonic flow is diminished until finally at $\alpha = -10°$ the subsonic region is confined to a small area about the vehicle nose. A comparison of forebody flows for air (fig. 9(a)) at $\alpha = 0°$ and CF_4 (fig. 9(b)) at $\alpha = 10°$ reveals that the flow field is predominately subsonic for both cases. Likewise, since the forebody flow characteristics are very similar, the pressure distributions reflect these similarities as observed in figures 7 ($\alpha = 0°$) and 8 ($\alpha = 10°$). A further example is noted when forebody flows for air (fig. 9(a)) at $\alpha = -10°$ and CF_4 (fig. 9(b)) at $\alpha = 0°$ are compared. At these angles of attack, the region of subsonic flow within the forebody shock layer has been greatly decreased. The extent to which the expansion of the flow about the skirt influences the surface pressure distributions is also greatly diminished and is observed in the pressure distributions presented in figures 7 and 8. (See, for example, $\alpha = -10°$ (fig. 7) and $\alpha = 0°$ (fig. 8).)

Changes in surface pressure brought about by variations in the flow field ultimately alter the aerodynamic characteristics of the vehicle as illustrated in references 12 and 14. For instance, of the basic aerodynamic forces and moments, the pitching-moment coefficient for this configuration is the most sensitive to variations in pressure distributions. By varying the surface pressure distribution caused by the variations in density ratio, the vehicle trims (point at which moments about the center of gravity are zero) at a substantially lower angle of attack in CF_4 than in air. (See fig. 10.) Also, greater longitudinal stability (more negative slope of pitching-moment coefficient versus angle of attack) is achieved from tests of this configuration performed in CF_4 over those performed in air. The wind tunnel results in CF_4 are believed to be a better simulation of flight data since the shock detachment distance (and ultimately the forebody flow field) is closer to the distance predicted for flight than air.

For the $\Phi = 225°$ ray (figs. 7(b) and 8(b)), the flow is observed to overexpand from the ellipsoid nose onto the cone section for $\alpha < 0°$ in air and for $\alpha \leq 5°$ in CF_4. Again, $C_p/C_{p,\mathrm{ref}}$ decreases as α is decreased. The pressure coefficient ratio along the $\Phi = 250°$ ray is less variant with angle of attack and is nearly the same (i.e., within ±2 percent) for $0° \leq \alpha \leq 10°$ in air. This is not true, however, for the CF_4 data, which exhibit trends similar to those observed for $\Phi = 225°$. Along the $\Phi = 270°$ ray (figs. 7(c) and 8(c)), which is orthogonal to the symmetry plane, values of $C_p/C_{p,\mathrm{ref}}$ for air and CF_4 are essentially independent of changes in angle of attack ($-10° \leq \alpha \leq 10°$) collapsing to within ±2.7 percent for $s/L < 0.4$. For the $\Phi = 290°$ and 315° rays, $C_p/C_{p,\mathrm{ref}}$ is again dependent on α and increases with decreasing α. This increase in pressure is consistent with the movement of the stagnation region farther up onto the ellipsoid nose as α becomes more negative.

As shown subsequently, the effect of angle of attack on base pressure coefficient was small.

Effect of Reynolds Number on Pressure Distributions

Pressure distributions for two values of Reynolds number in air, namely 2.05×10^5 and 6.61×10^5, are shown in figure 11. As expected, for this factor-of-4 variation in Reynolds number, there is a negligible effect on forebody pressure distributions; this was true for all angles of attack. However, Reynolds number does influence base pressures for the AFE as shown in figure 11(d) for air. The base pressure coefficient decreases with increasing Reynolds number over the range of angle of attack. Also, the difference in base pressure coefficient between the upper and lower orifices decreases with increasing Reynolds number. Similar results were noted for base pressure coefficients measured in CF_4. Sting interference effects on the present base pressures are unknown.

Effect of Normal Shock Density Ratio on Pressure Distributions

Pressure distributions at various angles of attack in air and CF_4 are presented in figures 12, 13, and 14. By generating a density ratio (ρ_2/ρ_∞) in CF_4 which is over twice that of ideal air, the CF_4 Tunnel simulates more closely the high density ratio aspect of dissociated equilibrium air which occurs in flight. (See refs. 7, 8, 19, and 26.) (This does not imply, however, that real-gas chemistry is simulated (ref. 27).) Thus, comparing CF_4 and air results provides a method for approximating equilibrium real-gas effects on pressure distributions of blunt bodies. As noted in the section "Test Conditions," free-stream Mach number and Reynolds number for the low pressure air condition and the CF_4 condition are nearly matched. Because the air data indicated a negligible effect of Reynolds number on measured forebody pressure distributions, data comparisons between air and CF_4 are assumed to be independent of Reynolds number.

As noted in figures 12(a), 13(a), and 14(a) for the $\Phi = 0°$ ray, the air and CF_4 data are in close agreement with one another; that is, both the air and CF_4 undergo similar expansions from the geometric stagnation point to the corner. Looking now at the $\Phi = 180°$ ray and $\alpha = 0°$ (fig. 12(a)), the CF_4 experiences an overexpansion of the flow from the elliptical nose onto the conical surface, whereas the air does not. For CF_4, $C_p/C_{p,\mathrm{ref}}$ is approximately 15 percent less at $s/L = 0.22$ than for air. Thus, typical of real-gas effects, the magnitude of the surface pressure in regions of compression such as the nose is relatively unaffected by an increase in density ratio; however, in regions of expansion such as those that occur as the flow moves off the nose onto the conical section, the pressure decreases because of an increase in density ratio or a decrease in ratio of specific heats. For $\alpha \leq 0°$ (figs. 12(a) and 13(a)), the CF_4 results recover to a nearly constant value of $C_p/C_{p,\mathrm{ref}}$ downstream of the overexpansion region (i.e., on the cone section: $0.4 < s/L < 0.76$), whereas the air results decrease monotonically to the corner. One explanation for the drop in pressure near the corner for air is the acceleration of the subsonic flow to a sonic condition. Recall that if the flow within the shock layer expands isentropically from the stagnation region, it becomes supersonic when $C_p/C_{p,\mathrm{ref}} < 0.5175$ for air and $C_p/C_{p,\mathrm{ref}} < 0.5658$ for CF_4. Thus, since the flow over the conical section for CF_4 has expanded closer to a sonic condition than for air, it requires less acceleration at the corner than air. Also, as discussed in a previous section, "Effect of Angle of Attack on Pressure Distributions," similar sonic line geometries are observed to produce similar pressure distributions (i.e., compare sonic line geometries for $\alpha = 0°$ in CF_4 (fig. 9(b)) and $\alpha = -10°$ in air (fig. 9(a)) and compare pressure distributions for $\alpha = 0°$ in CF_4 (fig. 12(a)) and $\alpha = -10°$ in air (fig. 13(a))). For these angles of attack, the amount of subsonic flow within the forebody shock layer has decreased significantly, and the extent to which the expansion of the flow about the skirt influences forebody pressure distributions has also decreased. Jones and Hunt (ref. 9) measured pressure distributions on a variety of large-angle sharp (sonic) corner cones in hypersonic air, CF_4, and helium flows. These findings for both sharp and blunted axisymmetric 50°, 60°, and 70° cones revealed trends similar to those of the present study between air and CF_4. When angle of attack is decreased to $-10°$ (fig. 13(a)) corresponding to a "less blunt" configuration from the perspective of the approaching free-stream flow, the effect of density ratio on the pressure distribution increases significantly in regions of expansion. Correspondingly, increasing α to 10° (fig. 14(a)) so that the body appears "more blunt" decreases the influence of density ratio on the pressure distribution. At $\alpha = -10°$, the pressure coefficient ratio decreases 25 percent at the nose-cone junction ($s/L = 0.22$) as the density ratio increases by a factor of 2. At $\alpha = 10°$, the effect of density ratio on $C_p/C_{p,\mathrm{ref}}$ is relatively small.

For the $\Phi = 225°$ and 250° rays and $\alpha = 0°, -10°$, and 10° (figs. 12(b), 13(b), and 14(b)), similar trends to those for $\Phi = 180°$ are observed for CF_4 as the flow overexpands from the elliptical nose onto the conical section. Again, the magnitude of this overexpansion on measured pressure decreases with increasing α. The CF_4 data are observed to recover to a slightly higher pressure at the corner, whereas the air data decrease monotonically downstream of the expansion region. The acceleration of the flow toward the sonic point naturally influences the characteristics of the flow in the corner region.

Data for the $\Phi = 270°, 290°$, and 315° rays over this same range of angle of attack are presented in figures 12(c), 13(c), and 14(c). For the $\Phi = 270°$ ray, where the flow expands off the elliptical nose onto a small portion of the cone and then expands to the corner, a slightly greater expansion from the geometrical stagnation point is observed for CF_4 than for air. Again, this is due to the influence of the cone section on the expansion over the nose. The remaining rays (290° and 315°) have relatively small cone sections. For these two rays, only slight variations are noted between the air and CF_4.

Comparison of Measured and Predicted Results

Measured and predicted pressure distributions for Mach 6 air and CF_4 are presented in figures 12, 13, and 14 for $\alpha = 0°, -10°$, and 10°, respectively. Pressure distributions calculated with modified Newtonian theory are also presented.

For the symmetry plane (figs. 12(a), 13(a), and 14(a)), the HALIS code accurately (3 to 4 percent) predicts the measured pressure distributions over the nose and cone section for air and CF_4. Comparisons between the modified Newtonian theory and the measured air and CF_4 data are in reasonably good agreement over the ellipsoidal nose but in poor agreement for the cone section. Qualitatively, the modified Newtonian theory predicts the trend of the measured CF_4 data better than the measured air data, as expected (ref. 28). In all cases, the modified Newtonian calculations and measured pressure data are within 9 percent for CF_4 and within 20 percent for air. This does not imply, however, that the pressure distributions and thus forces and moments (integrated pressures) are adequately predicted by using modified Newtonian theory. (See ref. 14.) For example, from figure 10, the HALIS code accurately predicts the pitching-moment characteristics for both air and CF_4 over the range of angle of attack. Also, trim angle of attack (angle of attack at which moments about the center of gravity are zero) is accurately predicted by the HALIS code. When pitching-moment coefficient is computed as a function of α for a flight trajectory point near perigee, assuming continuum flow in chemical equilibrium (HALIS (equilibrium air)), the predicted pitching-moment coefficient is only slightly larger in magnitude than the CF_4 wind tunnel data. When modified Newtonian theory is applied at this same flight trajectory point (Newtonian max q), the slopes of curves for pitching-moment coefficient versus α at $\alpha = 0°$ are nearly the same for HALIS (equilibrium air), CF_4, and modified Newtonian theory. However, trim angle of attack calculated with the modified Newtonian theory is considerably different from trim angle of attack calculated with HALIS (equilibrium air) and measured in CF_4. From the standpoint of magnitude, the CF_4 results are the best approximation to the flight values for pitching-moment coefficient for $\alpha \leq 5°$.

As noted in figures 12(b), 13(b), and 14(b) for the 225° ray ($\alpha = 0°, -10°$, and 10°, respectively), the HALIS code accurately (3 to 4 percent) predicts the measured pressure distributions in air. The HALIS calculations for CF_4 agree to within 4 percent of measured values for $s/L \leq 0.50$ and between 5 to 10 percent in the corner region ($s/L > 0.50$) over the range of angle of attack. For all cases, however, HALIS generally underpredicts measured pressures slightly in both air and CF_4. Again, good agreement is observed between measured pressure distributions and modified Newtonian prediction in the nose and shoulder regions, but Newtonian theory underpredicts pressures on the cone section.

For the 250° ray, the HALIS code slightly underpredicts measured pressures over the range of angle of attack in both air and CF_4. The magnitude of this underprediction in general is about 6 percent. This discrepancy tends to increase in the vicinity of the corner ($s/L > 0.45$) where the slope of the body (and thus the velocity gradient) is large. One possible explanation is the lack of sufficient grid resolution in the corner region. Calculations with the modified Newtonian theory are generally within 7 percent with both the air and CF_4 measurements over the range of angle of attack.

Comparisons between the present measurements and prediction for the $\Phi = 270°$, 290°, and 315° rays are shown in figures 12(c), 13(c), and 14(c) for angles of attack of 0°, $-10°$, and 10°, respectively. For both air and CF_4, HALIS qualitatively captures the measured data for all rays. In general, HALIS is in reasonable agreement (4 to 6 percent) with measurement over the range of angle of attack, but differences of 8 to 10 percent or greater are shown in some expansion regions near the corner. Again, these discrepancies could be the result of the grid resolution of the code in high velocity gradient areas. Better agreement between modified Newtonian theory and measurement is observed as α is decreased and as Φ progresses from the $\Phi = 270°$ ray to the $\Phi = 315°$ ray.

Concluding Remarks

The effects of normal shock density ratio (a real-gas simulation parameter) and Reynolds number on pressure distributions for the Aeroassist Flight Experiment (AFE) configuration were examined for angles of attack from $-10°$ to 10°. The high normal shock density ratio aspect of a real gas in thermochemical equilibrium was simulated at Mach 6 by testing in ideal air (density ratio equal to 5.25) and in CF_4 (density ratio equal to 12.0). Reynolds number per foot was varied from 0.60×10^6 to 2.2×10^6 in air. Pressure distributions predicted with modified Newtonian theory and a three-dimensional Euler code known as HALIS were compared with measurement for angles of attack of 0°, −10°, and 10°.

A significant effect of normal shock density ratio on pressure distributions in the nose-cone expansion region was observed. That is, typical of real-gas effects, the magnitude of the surface pressure in regions of compression such as the nose is relatively unaffected by an increase in density ratio; however, in regions of expansion such as those that occur as the flow moves off the nose onto the conical section, the pressure decreases because of an increase in density ratio. The magnitude of this effect decreased with increasing angle of attack (effective bluntness) for the range covered in these tests. The effect of Reynolds number on pressure distributions in air and CF_4 was negligible for forebody pressure distributions, but a measurable effect was noted on base pressures. Pressure distributions predicted with HALIS were in good agreement with measurement, whereas those predicted with modified Newtonian theory were in poor agreement over the cone section for air but in better agreement for CF_4 over the range of angle of attack.

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Table I. Nominal Test Conditions

$\mathrm{Re}_{\infty,L}$	$p_{t,1}$, psia	$T_{t,1}$, °R	p_∞, psia	T_∞, °R	M_∞	U_∞, fps	q_∞, psia	ρ_2/ρ_∞	$\mathrm{Re}_{2,L}$	$p_{t,2}$, psia	$T_{t,2}$, °R	γ_2
Langley 20-Inch Mach 6 Tunnel												
2.05×10^5	35	890	0.026	113.6	5.85	3054	0.62	5.25	0.33×10^5	1.16	890	1.40
6.61×10^5	126	926	0.083	114.3	5.96	3123	2.06	5.26	1.04×10^5	3.83	926	1.40
Langley Hypersonic CF_4 Tunnel												
1.76×10^5	2068	1201	0.054	313	6.25	2909	1.30	11.9	0.59×10^5	2.55	1188	1.11

Table II. Measured Pressure Distribution Data in Air at Mach 5.85 for Low Reservoir Pressure Condition

(a) $\alpha = -10°$

$$\left[\begin{array}{c} p_{t,1} = 35.29 \text{ psi};\ T_{t,1} = 882.7°\text{R};\ p_{t,2} = 1.1619 \text{ psi};\ M_\infty = 5.850;\ p_\infty = 0.0261 \text{ psi};\ q_\infty = 0.6254 \text{ psi}; \\ T_\infty = 112.5°\text{R};\ \rho_\infty = 1.947 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3042 \text{ fps};\ \text{Re}_{\infty,L} = 209\,373;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\text{max}}$	$C_p/C_{p,\text{ref}}$
0	0.0000	1.1502	1.7974	0.9897	0.971
0	−0.0545	1.1798	1.8447	1.0158	0.9965
0	−0.1091	1.2024	1.8809	1.0357	1.016
0	−0.1636	1.0532	1.6423	0.9043	0.8872
0	−0.2182	0.8952	1.3897	0.7652	0.7507
0	−0.2727	0.3454	0.5106	0.2811	0.2758
180	0.0545	1.0712	1.6711	0.9201	0.9027
180	0.1091	0.9822	1.5288	0.8418	0.8258
180	0.1636	0.8822	1.3689	0.7537	0.7395
180	0.2182	0.8231	1.2743	0.7017	0.6883
180	0.2727	0.8327	1.2897	0.7102	0.6967
180	0.3272	0.8409	1.3028	0.7174	0.7038
180	0.3818	0.842	1.3046	0.7183	0.7047
180	0.4363	0.8438	1.3075	0.7199	0.7062
180	0.4909	0.848	1.3142	0.7236	0.7099
180	0.5454	0.8352	1.2937	0.7124	0.6989
180	0.5999	0.8184	1.2669	0.6976	0.6844
180	0.6545	0.8015	1.2398	0.6827	0.6698
180	0.709	0.7504	1.1581	0.6377	0.6256
180	0.7636	0.4663	0.7039	0.3876	0.3802
180	0.8181	0.088	0.099	0.0545	0.0535
0/225	0.0000	1.1502	1.7974	0.9897	0.971
225	0.0545	1.116	1.7427	0.9596	0.9413
225	0.1091	0.9909	1.5427	0.8494	0.8334
225	0.1636	0.9488	1.4754	0.8124	0.797
225	0.2182	0.8652	1.3417	0.7388	0.7248
225	0.2727	0.874	1.3558	0.7465	0.7324
225	0.3272	0.8502	1.3177	0.7256	0.7118
225	0.3818	0.8684	1.3468	0.7416	0.7276
225	0.4363	0.8614	1.3356	0.7354	0.7215
225	0.4909	0.8513	1.3195	0.7265	0.7128
225	0.5454	0.8258	1.2787	0.7041	0.6908
225	0.5999	0.7476	1.1537	0.6352	0.6232
225	0.6545	0.5297	0.8052	0.4434	0.435
225	0.709	0.0914	0.1044	0.0575	0.0564
0/250	0.0000	1.1502	1.7974	0.9897	0.971
250	0.1091	1.0787	1.6831	0.9267	0.9092
250	0.1636	1.0266	1.5998	0.8809	0.8642
250	0.2182	0.9615	1.4957	0.8236	0.808
250	0.2727	0.9185	1.4269	0.7857	0.7708
250	0.3272	0.8853	1.3738	0.7565	0.7421
250	0.3818	0.8825	1.3693	0.754	0.7396
250	0.4363	0.8852	1.3737	0.7564	0.7421
250	0.4909	0.7976	1.2336	0.6793	0.6664
250	0.5454	0.3577	0.5302	0.292	0.2864
250	0.5999	0.0836	0.0919	0.0506	0.0497

Table II. Continued

(a) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	1.1502	1.7974	0.9897	0.971
270	0.1091	1.1471	1.7925	0.987	0.9683
270	0.1636	1.1012	1.7191	0.9466	0.9286
270	0.2182	1.0426	1.6254	0.895	0.878
270	0.2727	0.9913	1.5433	0.8498	0.8337
270	0.3272	0.9562	1.4872	0.8189	0.8034
270	0.3818	0.8932	1.3865	0.7634	0.749
270	0.4363	0.4941	0.7483	0.412	0.4042
270	0.4909	0.1404	0.1828	0.1006	0.0987
0/290	0.0000	1.1502	1.7974	0.9897	0.971
290	0.1091	1.1213	1.7512	0.9643	0.946
290	0.1636	1.1244	1.7562	0.967	0.9487
290	0.2182	1.0971	1.7125	0.9429	0.9251
290	0.2727	0.9819	1.5283	0.8415	0.8256
290	0.3272	0.872	1.3526	0.7448	0.7307
290	0.3818	0.2857	0.4151	0.2286	0.2242
0/315	0.0000	1.1502	1.7974	0.9897	0.971
315	0.0545	1.188	1.8579	1.023	1.0036
315	0.1091	1.1489	1.7953	0.9885	0.9697
315	0.1636	1.1521	1.8004	0.9914	0.9726
315	0.2182	1.0343	1.6121	0.8877	0.8708
315	0.2727	0.7981	1.2344	0.6797	0.6668
315	0.3272	0.2683	0.3873	0.2132	0.2092
Base		0.0272	0.0018	0.001	0.001
Base		0.0544	0.0453	0.0249	0.0244

Table II. Continued

(b) $\alpha = -5°$

$\left[p_{t,1} = 35.3 \text{ psi};\ T_{t,1} = 882.7°\text{R};\ p_{t,2} = 1.1636 \text{ psi};\ M_\infty = 5.848;\ p_\infty = 0.0262 \text{ psi};\ q_\infty = 0.6263 \text{ psi}; \right.$
$\left. T_\infty = 112.6°\text{R};\ \rho_\infty = 1.949 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3042 \text{ fps};\ \text{Re}_{\infty,L} = 209\,556;\ \gamma_\infty = 1.4 \right]$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	1.1818	1.8451	1.016	0.9968
0	−0.0545	1.183	1.847	1.0171	0.9978
0	−0.1091	1.1766	1.8368	1.0114	0.9923
0	−0.1636	0.9986	1.5526	0.8549	0.8387
0	−0.2182	0.817	1.2627	0.6953	0.6821
0	−0.2727	0.2755	0.3981	0.2192	0.215
180	0.0545	1.1318	1.7653	0.972	0.9536
180	0.1091	1.0726	1.6708	0.92	0.9026
180	0.1636	1.0077	1.5671	0.8629	0.8466
180	0.2182	0.9506	1.4759	0.8127	0.7972
180	0.2727	0.9644	1.498	0.8249	0.8092
180	0.3272	0.9603	1.4915	0.8213	0.8057
180	0.3818	0.95	1.475	0.8122	0.7968
180	0.4363	0.9342	1.4498	0.7983	0.7831
180	0.4909	0.9406	1.46	0.8039	0.7887
180	0.5454	0.9202	1.4274	0.786	0.7711
180	0.5999	0.8958	1.3885	0.7646	0.7501
180	0.6545	0.8692	1.346	0.7412	0.7271
180	0.709	0.8053	1.244	0.685	0.672
180	0.7636	0.4952	0.7488	0.4123	0.4045
180	0.8181	0.095	0.1099	0.0605	0.0593
0/225	0.0000	1.1818	1.8451	1.016	0.9968
225	0.0545	1.1479	1.791	0.9862	0.9674
225	0.1091	1.0626	1.6548	0.9112	0.8939
225	0.1636	1.0461	1.6285	0.8967	0.8797
225	0.2182	0.9893	1.5378	0.8468	0.8307
225	0.2727	0.9891	1.5374	0.8466	0.8306
225	0.3272	0.9579	1.4876	0.8191	0.8036
225	0.3818	0.9684	1.5044	0.8284	0.8127
225	0.4363	0.953	1.4798	0.8148	0.7994
225	0.4909	0.9339	1.4493	0.798	0.7829
225	0.5454	0.9013	1.3973	0.7694	0.7548
225	0.5999	0.8125	1.2555	0.6913	0.6782
225	0.6545	0.571	0.8699	0.479	0.4699
225	0.709	0.1027	0.1221	0.0673	0.066
0/250	0.0000	1.1818	1.8451	1.016	0.9968
250	0.1091	1.1304	1.7631	0.9708	0.9524
250	0.1636	1.0876	1.6947	0.9332	0.9155
250	0.2182	1.036	1.6123	0.8878	0.871
250	0.2727	0.9985	1.5525	0.8548	0.8387
250	0.3272	0.9613	1.4931	0.8221	0.8066
250	0.3818	0.9558	1.4843	0.8173	0.8017
250	0.4363	0.9461	1.4688	0.8088	0.7935
250	0.4909	0.8484	1.3128	0.7229	0.7092
250	0.5454	0.3691	0.5475	0.3015	0.2958
250	0.5999	0.0845	0.0931	0.0513	0.0503

Table II. Continued

(b) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	1.1818	1.8451	1.016	0.9968
270	0.1091	1.1765	1.8367	1.0113	0.9922
270	0.1636	1.1312	1.7643	0.9715	0.9531
270	0.2182	1.0766	1.6772	0.9235	0.906
270	0.2727	1.0244	1.5938	0.8776	0.861
270	0.3272	0.9874	1.5347	0.8451	0.8291
270	0.3818	0.9149	1.419	0.7813	0.7665
270	0.4363	0.48	0.7246	0.399	0.3914
270	0.4909	0.1243	0.1566	0.0862	0.0846
0/290	0.0000	1.1818	1.8451	1.016	0.9968
290	0.1091	1.1333	1.7677	0.9734	0.9549
290	0.1636	1.1261	1.7562	0.967	0.9487
290	0.2182	1.0878	1.695	0.9334	0.9157
290	0.2727	0.9706	1.5079	0.8303	0.8146
290	0.3272	0.8476	1.3115	0.7222	0.7085
290	0.3818	0.2453	0.3498	0.1926	0.189
0/315	0.0000	1.1818	1.8451	1.016	0.9968
315	0.0545	1.1985	1.8718	1.0307	1.0112
315	0.1091	1.1373	1.774	0.9768	0.9582
315	0.1636	1.1222	1.75	0.9636	0.9454
315	0.2182	0.9903	1.5394	0.8476	0.8316
315	0.2727	0.7371	1.1351	0.625	0.6132
315	0.3272	0.2188	0.3075	0.1693	0.1661
Base		0.029	0.0045	0.0025	0.0024
Base		0.0559	0.0474	0.0261	0.0256

Table II. Continued

(c) $\alpha = 0°$

$$\left[\begin{array}{c} p_{t,1} = 33.77 \text{ psi};\ T_{t,1} = 885.7°\text{R};\ p_{t,2} = 1.1220 \text{ psi};\ M_\infty = 5.837;\ p_\infty = 0.0253 \text{ psi};\ q_\infty = 0.6038 \text{ psi}; \\ T_\infty = 113.3°\text{R};\ \rho_\infty = 1.874 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3046 \text{ fps};\ \text{Re}_{\infty,L} = 200\,229;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	1.1432	1.8514	1.0193	1.0000
0	−0.0545	1.1299	1.8294	1.0072	0.9881
0	−0.1091	1.0938	1.7696	0.9743	0.9558
0	−0.1636	0.9043	1.4558	0.8015	0.7863
0	−0.2182	0.7215	1.153	0.6348	0.6228
0	−0.2727	0.2123	0.3097	0.1705	0.1673
180	0.0545	1.1319	1.8327	1.009	0.9899
180	0.1091	1.1002	1.7802	0.9801	0.9616
180	0.1636	1.0686	1.7279	0.9513	0.9333
180	0.2182	1.0191	1.6459	0.9062	0.889
180	0.2727	1.0219	1.6505	0.9087	0.8915
180	0.3272	1.0093	1.6297	0.8972	0.8802
180	0.3818	0.9813	1.5833	0.8717	0.8552
180	0.4363	0.9764	1.5752	0.8672	0.8508
180	0.4909	0.9745	1.572	0.8655	0.8491
180	0.5454	0.9497	1.531	0.8429	0.8269
180	0.5999	0.9202	1.4821	0.816	0.8005
180	0.6545	0.8872	1.4275	0.7859	0.771
180	0.709	0.8163	1.31	0.7213	0.7076
180	0.7636	0.5033	0.7917	0.4359	0.4276
180	0.8181	0.102	0.127	0.0699	0.0686
0/225	0.0000	1.1432	1.8514	1.0193	1.0000
225	0.0545	1.1388	1.8442	1.0153	0.9961
225	0.1091	1.0862	1.757	0.9674	0.949
225	0.1636	1.0865	1.7575	0.9676	0.9493
225	0.2182	1.0446	1.6881	0.9294	0.9118
225	0.2727	1.0341	1.6708	0.9199	0.9024
225	0.3272	1.0026	1.6186	0.8911	0.8743
225	0.3818	1.0029	1.6191	0.8914	0.8745
225	0.4363	0.9797	1.5807	0.8702	0.8538
225	0.4909	0.9561	1.5416	0.8487	0.8327
225	0.5454	0.9203	1.4823	0.8161	0.8006
225	0.5999	0.8348	1.3407	0.7381	0.7241
225	0.6545	0.5817	0.9215	0.5073	0.4977
225	0.709	0.113	0.1452	0.08	0.0785
0/250	0.0000	1.1432	1.8514	1.0193	1.0000
250	0.1091	1.118	1.8097	0.9964	0.9775
250	0.1636	1.0963	1.7738	0.9766	0.9581
250	0.2182	1.056	1.707	0.9398	0.922
250	0.2727	1.0221	1.6509	0.9089	0.8917
250	0.3272	0.97	1.5646	0.8614	0.8451
250	0.3818	0.9686	1.5622	0.8601	0.8438
250	0.4363	0.9508	1.5328	0.8439	0.8279
250	0.4909	0.8479	1.3624	0.7501	0.7359
250	0.5454	0.3605	0.5552	0.3056	0.2999
250	0.5999	0.0803	0.0911	0.0502	0.0492

Table II. Continued

(c) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\text{max}}$	$C_p/C_{p,\text{ref}}$
0/270	0.0000	1.1432	1.8514	1.0193	1.0000
270	0.1091	1.1367	1.8407	1.0134	0.9942
270	0.1636	1.1052	1.7885	0.9847	0.966
270	0.2182	1.052	1.7004	0.9362	0.9184
270	0.2727	1.0075	1.6267	0.8956	0.8786
270	0.3272	0.9664	1.5586	0.8581	0.8419
270	0.3818	0.8901	1.4323	0.7885	0.7736
270	0.4363	0.432	0.6736	0.3708	0.3638
270	0.4909	0.1073	0.1358	0.0748	0.0734
0/290	0.0000	1.1432	1.8514	1.0193	1.0000
290	0.1091	1.093	1.7683	0.9736	0.9551
290	0.1636	1.078	1.7435	0.9599	0.9417
290	0.2182	1.0254	1.6563	0.9119	0.8947
290	0.2727	0.9224	1.4858	0.818	0.8025
290	0.3272	0.7887	1.2643	0.6961	0.6829
290	0.3818	0.2026	0.2936	0.1617	0.1586
0/315	0.0000	1.1432	1.8514	1.0193	1.0000
315	0.0545	1.1441	1.8529	1.0202	1.0008
315	0.1091	1.08	1.7468	0.9617	0.9435
315	0.1636	1.0453	1.6893	0.9301	0.9125
315	0.2182	0.9116	1.4679	0.8082	0.7928
315	0.2727	0.6612	1.0532	0.5798	0.5689
315	0.3272	0.1691	0.2382	0.1311	0.1286
Base		0.0338	0.0141	0.0078	0.0076
Base		0.0581	0.0543	0.0299	0.0293

Table II. Continued

(d) $\alpha = 5°$

$$\left[\begin{array}{c} p_{t,1} = 34.92 \text{ psi};\ T_{t,1} = 888.7°\text{R};\ p_{t,2} = 1.1551 \text{ psi};\ M_\infty = 5.843;\ p_\infty = 0.0260 \text{ psi};\ q_\infty = 0.6217 \text{ psi}; \\ T_\infty = 113.5°\text{R};\ \rho_\infty = 1.922 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3052 \text{ fps};\ \text{Re}_{\infty,L} = 205\,397;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	1.1645	1.8313	1.0083	0.9892
0	−0.0545	1.1175	1.7557	0.9667	0.9484
0	−0.1091	1.0535	1.6527	0.91	0.8928
0	−0.1636	0.8445	1.3166	0.7249	0.7112
0	−0.2182	0.6484	1.0011	0.5512	0.5408
0	−0.2727	0.1686	0.2294	0.1263	0.1239
180	0.0545	1.1739	1.8464	1.0167	0.9974
180	0.1091	1.1736	1.8459	1.0164	0.9971
180	0.1636	1.1616	1.8266	1.0058	0.9867
180	0.2182	1.1122	1.7472	0.962	0.9437
180	0.2727	1.114	1.75	0.9636	0.9454
180	0.3272	1.0957	1.7206	0.9474	0.9295
180	0.3818	1.0766	1.6899	0.9305	0.9129
180	0.4363	1.055	1.6552	0.9114	0.894
180	0.4909	1.053	1.6519	0.9096	0.8924
180	0.5454	1.0243	1.6058	0.8842	0.8674
180	0.5999	0.9911	1.5524	0.8548	0.8386
180	0.6545	0.9533	1.4916	0.8213	0.8057
180	0.709	0.8756	1.3666	0.7525	0.7382
180	0.7636	0.5434	0.8322	0.4582	0.4496
180	0.8181	0.1182	0.1483	0.0817	0.0801
0/225	0.0000	1.1645	1.8313	1.0083	0.9892
225	0.0545	1.1708	1.8414	1.0139	0.9946
225	0.1091	1.1376	1.788	0.9845	0.9659
225	0.1636	1.1551	1.8161	1.0000	0.9811
225	0.2182	1.1271	1.7711	0.9752	0.9567
225	0.2727	1.1106	1.7446	0.9606	0.9424
225	0.3272	1.0692	1.678	0.9239	0.9064
225	0.3818	1.0685	1.6769	0.9233	0.9058
225	0.4363	1.0433	1.6363	0.901	0.8839
225	0.4909	1.0173	1.5945	0.878	0.8613
225	0.5454	0.977	1.5297	0.8423	0.8263
225	0.5999	0.884	1.3801	0.7599	0.7455
225	0.6545	0.6237	0.9614	0.5294	0.5193
225	0.709	0.1231	0.1562	0.086	0.0844
0/250	0.0000	1.1645	1.8313	1.0083	0.9892
250	0.1091	1.1542	1.8147	0.9992	0.9803
250	0.1636	1.1321	1.7792	0.9796	0.9611
250	0.2182	1.1022	1.7311	0.9531	0.9351
250	0.2727	1.0662	1.6732	0.9213	0.9038
250	0.3272	1.0184	1.5963	0.8789	0.8623
250	0.3818	1.0074	1.5785	0.8691	0.8526
250	0.4363	0.9862	1.5445	0.8504	0.8343
250	0.4909	0.8786	1.3714	0.7551	0.7408
250	0.5454	0.3635	0.5429	0.2989	0.2933
250	0.5999	0.0767	0.0816	0.0449	0.0441

Table II. Continued

(d) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\mathrm{max}}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	1.1645	1.8313	1.0083	0.9892
270	0.1091	1.1575	1.82	1.0021	0.9832
270	0.1636	1.1161	1.7534	0.9655	0.9472
270	0.2182	1.0649	1.6711	0.9201	0.9027
270	0.2727	1.0151	1.591	0.876	0.8594
270	0.3272	0.9696	1.5178	0.8357	0.8199
270	0.3818	0.8876	1.3859	0.7631	0.7486
270	0.4363	0.4213	0.6358	0.3501	0.3435
270	0.4909	0.092	0.1062	0.0585	0.0573
0/290	0.0000	1.1645	1.8313	1.0083	0.9892
290	0.1091	1.0875	1.7074	0.9401	0.9223
290	0.1636	1.0592	1.6619	0.9151	0.8977
290	0.2182	1.0042	1.5734	0.8664	0.8499
290	0.2727	0.8945	1.397	0.7692	0.7546
290	0.3272	0.7593	1.1795	0.6495	0.6372
290	0.3818	0.1712	0.2336	0.1286	0.1262
0/315	0.0000	1.1645	1.8313	1.0083	0.9892
315	0.0545	1.144	1.7983	0.9902	0.9714
315	0.1091	1.0578	1.6596	0.9138	0.8964
315	0.1636	1.0008	1.568	0.8633	0.847
315	0.2182	0.8528	1.3299	0.7323	0.7184
315	0.2727	0.6001	0.9234	0.5085	0.4988
315	0.3272	0.1399	0.1832	0.1009	0.099
Base		0.0316	0.009	0.005	0.0049
Base		0.0545	0.0458	0.0252	0.0248

Table II. Continued

(e) $\alpha = 10°$

$$\left[\begin{array}{c} p_{t,1} = 35.25 \text{ psi};\ T_{t,1} = 885.7°\text{R};\ p_{t,2} = 1.1638 \text{ psi};\ M_\infty = 5.846;\ p_\infty = 0.0262 \text{ psi};\ q_\infty = 0.6264 \text{ psi}; \\ T_\infty = 113.0°\text{R};\ \rho_\infty = 1.943 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3047 \text{ fps};\ \text{Re}_{\infty,L} = 208\,303;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	1.1382	1.7752	0.9775	0.959
0	−0.0545	1.067	1.6616	0.9149	0.8976
0	−0.1091	0.9871	1.534	0.8447	0.8287
0	−0.1636	0.7651	1.1796	0.6495	0.6372
0	−0.2182	0.57	0.8681	0.478	0.469
0	−0.2727	0.1381	0.1786	0.0984	0.0965
180	0.0545	1.1665	1.8204	1.0024	0.9834
180	0.1091	1.1915	1.8603	1.0243	1.005
180	0.1636	1.2023	1.8776	1.0338	1.0143
180	0.2182	1.1729	1.8307	1.008	0.9888
180	0.2727	1.1661	1.8198	1.002	0.983
180	0.3272	1.1465	1.7885	0.9848	0.9661
180	0.3818	1.1286	1.7599	0.9691	0.9507
180	0.4363	1.1149	1.7381	0.9571	0.9388
180	0.4909	1.1029	1.7189	0.9465	0.9285
180	0.5454	1.0761	1.6761	0.9229	0.9054
180	0.5999	1.041	1.6201	0.8921	0.8752
180	0.6545	1.0033	1.5599	0.8589	0.8427
180	0.709	0.9214	1.4291	0.7869	0.772
180	0.7636	0.5891	0.8986	0.4948	0.4854
180	0.8181	0.1454	0.1903	0.1048	0.1028
0/225	0.0000	1.1382	1.7752	0.9775	0.959
225	0.0545	1.1643	1.817	1.0005	0.9814
225	0.1091	1.1392	1.7768	0.9784	0.9599
225	0.1636	1.1736	1.8317	1.0086	0.9895
225	0.2182	1.1605	1.8108	0.9971	0.9782
225	0.2727	1.144	1.7845	0.9826	0.964
225	0.3272	1.0999	1.7141	0.9438	0.926
225	0.3818	1.1023	1.7179	0.9459	0.928
225	0.4363	1.077	1.6775	0.9237	0.9062
225	0.4909	1.0508	1.6357	0.9007	0.8836
225	0.5454	1.0103	1.571	0.8651	0.8487
225	0.5999	0.9123	1.4146	0.7789	0.7642
225	0.6545	0.6525	0.9998	0.5505	0.5401
225	0.709	0.136	0.1753	0.0965	0.0947
0/250	0.0000	1.1382	1.7752	0.9775	0.959
250	0.1091	1.1397	1.7776	0.9788	0.9603
250	0.1636	1.1267	1.7569	0.9674	0.9491
250	0.2182	1.1047	1.7217	0.948	0.9301
250	0.2727	1.0671	1.6617	0.915	0.8977
250	0.3272	1.0202	1.5868	0.8738	0.8572
250	0.3818	1.0193	1.5854	0.8729	0.8563
250	0.4363	0.9897	1.5382	0.847	0.8309
250	0.4909	0.8812	1.3649	0.7516	0.7374
250	0.5454	0.3599	0.5327	0.2933	0.2878
250	0.5999	0.0759	0.0793	0.0437	0.0429

Table II. Concluded

(e) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	1.1382	1.7752	0.9775	0.959
270	0.1091	1.1291	1.7607	0.9695	0.9511
270	0.1636	1.0867	1.693	0.9322	0.9146
270	0.2182	1.0368	1.6133	0.8884	0.8715
270	0.2727	0.9869	1.5337	0.8445	0.8285
270	0.3272	0.941	1.4604	0.8041	0.7889
270	0.3818	0.8604	1.3317	0.7333	0.7194
270	0.4363	0.395	0.5888	0.3242	0.3181
270	0.4909	0.0847	0.0934	0.0514	0.0505
0/290	0.0000	1.1382	1.7752	0.9775	0.959
290	0.1091	1.0426	1.6226	0.8935	0.8765
290	0.1636	1.0088	1.5686	0.8637	0.8474
290	0.2182	0.9538	1.4808	0.8154	0.8
290	0.2727	0.8431	1.3041	0.7181	0.7045
290	0.3272	0.7164	1.1019	0.6067	0.5952
290	0.3818	0.1474	0.1935	0.1065	0.1045
0/315	0.0000	1.1382	1.7752	0.9775	0.959
315	0.0545	1.1007	1.7154	0.9445	0.9266
315	0.1091	1.004	1.5609	0.8595	0.8431
315	0.1636	0.9337	1.4488	0.7977	0.7826
315	0.2182	0.7818	1.2063	0.6642	0.6516
315	0.2727	0.5368	0.8151	0.4488	0.4403
315	0.3272	0.1218	0.1526	0.084	0.0824
Base		0.0313	0.0081	0.0045	0.0044
Base		0.055	0.046	0.0253	0.0248

Table III. Measured Pressure Distribution Data in Air at Mach 5.96 for High Reservoir Pressure Condition

(a) $\alpha = -10°$

$$\left[\begin{array}{c} p_{t,1} = 126.6 \text{ psi};\ T_{t,1} = 924.7°\text{R};\ p_{t,2} = 3.8204 \text{ psi};\ M_\infty = 5.974;\ p_\infty = 0.0823 \text{ psi};\ q_\infty = 2.0570 \text{ psi}; \\ T_\infty = 113.6°\text{R};\ \rho_\infty = 6.079 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3122 \text{ fps};\ \text{Re}_{\infty,L} = 663658;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	3.7620	1.7891	0.9844	0.9696
0	−0.0545	3.8305	1.8224	1.0027	0.9877
0	−0.1091	3.8806	1.8468	1.0161	1.0009
0	−0.1636	3.5725	1.6970	0.9337	0.9197
0	−0.2182	2.9165	1.3780	0.7582	0.7468
0	−0.2727	1.0856	0.4878	0.2684	0.2644
180	0.0545	3.5211	1.6720	0.9199	0.9062
180	0.1091	3.2174	1.5243	0.8387	0.8261
180	0.1636	2.8556	1.3484	0.7419	0.7308
180	0.2182	2.6856	1.2656	0.6964	0.6860
180	0.2727	2.7120	1.2786	0.7035	0.6930
180	0.3272	2.7464	1.2953	0.7127	0.7020
180	0.3818	2.7433	1.2938	0.7119	0.7012
180	0.4363	2.7968	1.3197	0.7262	0.7153
180	0.4909	2.7693	1.3065	0.7188	0.7081
180	0.5454	2.7456	1.2949	0.7125	0.7018
180	0.5999	2.7110	1.2781	0.7032	0.6927
180	0.6545	2.6560	1.2514	0.6885	0.6782
180	0.7090	2.5019	1.1764	0.6473	0.6376
180	0.7636	1.5512	0.7142	0.3930	0.3871
180	0.8181	0.2763	0.0943	0.0519	0.0511
0/225	0.0000	3.7620	1.7891	0.9844	0.9696
225	0.0545	3.6442	1.7316	0.9529	0.9386
225	0.1091	3.3272	1.5777	0.8681	0.8551
225	0.1636	3.1018	1.4681	0.8078	0.7957
225	0.2182	2.7916	1.3173	0.7248	0.7139
225	0.2727	2.8341	1.3380	0.7361	0.7251
225	0.3272	2.8341	1.3380	0.7361	0.7251
225	0.3818	2.8447	1.3431	0.7390	0.7279
225	0.4363	2.8288	1.3354	0.7347	0.7237
225	0.4909	2.7881	1.3156	0.7238	0.7130
225	0.5454	2.7069	1.2761	0.7021	0.6916
225	0.5999	2.5061	1.1785	0.6484	0.6387
225	0.6545	1.6975	0.7853	0.4321	0.4256
225	0.7090	0.2975	0.1046	0.0576	0.0567
0/250	0.0000	3.7620	1.7891	0.9844	0.9696
250	0.1091	3.5263	1.6745	0.9213	0.9075
250	0.1636	3.3639	1.5956	0.8779	0.8647
250	0.2182	3.1159	1.4750	0.8115	0.7994
250	0.2727	3.0224	1.4295	0.7865	0.7747
250	0.3272	2.9739	1.4059	0.7735	0.7620
250	0.3818	2.9555	1.3968	0.7686	0.7571
250	0.4363	2.8797	1.3601	0.7483	0.7371
250	0.4909	2.6218	1.2347	0.6794	0.6692
250	0.5454	1.1299	0.5094	0.2802	0.2761
250	0.5999	0.2454	0.0793	0.0436	0.0430

Table III. Continued

(a) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	3.7620	1.7891	0.9844	0.9696
270	0.1091	3.6652	1.7421	0.9585	0.9441
270	0.1636	3.5568	1.6894	0.9295	0.9156
270	0.2182	3.3614	1.5944	0.8772	0.8641
270	0.2727	3.2190	1.5251	0.8391	0.8266
270	0.3272	3.1275	1.4806	0.8146	0.8024
270	0.3818	2.9011	1.3705	0.7541	0.7428
270	0.4363	1.5959	0.7359	0.4049	0.3988
270	0.4909	0.4237	0.1660	0.0913	0.0900
0/290	0.0000	3.7620	1.7891	0.9844	0.9696
290	0.1091	3.7028	1.7603	0.9685	0.9540
290	0.1636	3.6711	1.7449	0.9601	0.9457
290	0.2182	3.4881	1.6560	0.9111	0.8975
290	0.2727	3.2330	1.5319	0.8429	0.8302
290	0.3272	2.7853	1.3142	0.7231	0.7123
290	0.3818	0.8769	0.3863	0.2126	0.2094
0/315	0.0000	3.7620	1.7891	0.9844	0.9696
315	0.0545	3.8251	1.8198	1.0013	0.9863
315	0.1091	3.7904	1.8027	0.992	0.9771
315	0.1636	3.7239	1.7706	0.9742	0.9596
315	0.2182	3.4031	1.6146	0.8884	0.8751
315	0.2727	2.6327	1.2400	0.6823	0.6721
315	0.3272	0.7677	0.3333	0.1834	0.1806
Base		0.0692	−0.0064	−0.0035	−0.0035
Base		0.0947	0.0060	0.0033	0.0033

Table III. Continued

(b) $\alpha = -5°$

$$\left[\begin{array}{c} p_{t,1} = 126.3 \text{ psi};\ T_{t,1} = 924.7°\text{R};\ p_{t,2} = 3.8210 \text{ psi};\ M_\infty = 5.970;\ p_\infty = 0.0824 \text{ psi};\ q_\infty = 2.0570 \text{ psi}; \\ T_\infty = 113.8°\text{R};\ \rho_\infty = 6.081 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3121 \text{ fps};\ \text{Re}_{\infty,L} = 663\,046;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0	0.0000	3.85	1.8315	1.0078	0.9927
0	−0.0545	3.8354	1.8244	1.0039	0.9888
0	−0.1091	3.817	1.8155	0.9989	0.984
0	−0.1636	3.3811	1.6036	0.8823	0.8691
0	−0.2182	2.6653	1.2556	0.6909	0.6805
0	−0.2727	0.8541	0.3751	0.2064	0.2033
180	0.0545	3.6928	1.7551	0.9657	0.9513
180	0.1091	3.4963	1.6596	0.9131	0.8995
180	0.1636	3.2883	1.5585	0.8575	0.8447
180	0.2182	3.1669	1.4995	0.8251	0.8128
180	0.2727	3.1625	1.4973	0.8239	0.8115
180	0.3272	3.1517	1.4921	0.821	0.8087
180	0.3818	3.0975	1.4657	0.8065	0.7944
180	0.4363	3.1142	1.4739	0.8109	0.7989
180	0.4909	3.0811	1.4577	0.8021	0.7901
180	0.5454	3.0262	1.431	0.7874	0.7756
180	0.5999	2.9606	1.3992	0.7699	0.7583
180	0.6545	2.8697	1.355	0.7455	0.7344
180	0.709	2.6691	1.2574	0.6919	0.6815
180	0.7636	1.6331	0.7538	0.4148	0.4086
180	0.8181	0.2931	0.1024	0.0564	0.0555
0/225	0.0000	3.85	1.8315	1.0078	0.9927
225	0.0545	3.7889	1.8019	0.9914	0.9767
225	0.1091	3.5427	1.6821	0.9256	0.9117
225	0.1636	3.4308	1.6277	0.8956	0.8822
225	0.2182	3.2191	1.5248	0.839	0.8264
225	0.2727	3.2273	1.5288	0.8412	0.8286
225	0.3272	3.1932	1.5122	0.8321	0.8196
225	0.3818	3.1796	1.5056	0.8284	0.816
225	0.4363	3.1345	1.4837	0.8164	0.8042
225	0.4909	3.0671	1.4509	0.7983	0.7864
225	0.5454	2.9567	1.3973	0.7688	0.7573
225	0.5999	2.7197	1.282	0.7054	0.6949
225	0.6545	1.8388	0.8538	0.4698	0.4628
225	0.709	0.329	0.1199	0.066	0.065
0/250	0.0000	3.85	1.8315	1.0078	0.9927
250	0.1091	3.6728	1.7454	0.9604	0.946
250	0.1636	3.5736	1.6971	0.9338	0.9198
250	0.2182	3.3794	1.6027	0.8819	0.8687
250	0.2727	3.2947	1.5616	0.8592	0.8464
250	0.3272	3.206	1.5184	0.8355	0.823
250	0.3818	3.1662	1.4992	0.8248	0.8126
250	0.4363	3.0865	1.4604	0.8035	0.7915
250	0.4909	2.7878	1.3152	0.7236	0.7128
250	0.5454	1.1633	0.5254	0.2891	0.2848
250	0.5999	0.2389	0.0761	0.0419	0.0412

Table III. Continued

(b) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	3.85	1.8315	1.0078	0.9927
270	0.1091	3.7508	1.7833	0.9812	0.9665
270	0.1636	3.6673	1.7427	0.9589	0.9445
270	0.2182	3.4783	1.6508	0.9083	0.8947
270	0.2727	3.343	1.585	0.8721	0.8591
270	0.3272	3.2343	1.5322	0.8431	0.8304
270	0.3818	2.9807	1.4089	0.7752	0.7636
270	0.4363	1.5478	0.7124	0.392	0.3861
270	0.4909	0.3715	0.1405	0.0773	0.0762
0/290	0.0000	3.85	1.8315	1.0078	0.9927
290	0.1091	3.7305	1.7734	0.9758	0.9612
290	0.1636	3.6888	1.7531	0.9646	0.9502
290	0.2182	3.4781	1.6507	0.9083	0.8947
290	0.2727	3.2104	1.5206	0.8367	0.8241
290	0.3272	2.7229	1.2836	0.7063	0.6957
290	0.3818	0.7383	0.3188	0.1754	0.1728
0/315	0.0000	3.85	1.8315	1.0078	0.9927
315	0.0545	3.8529	1.8329	1.0085	0.9934
315	0.1091	3.7464	1.7813	0.9801	0.9655
315	0.1636	3.644	1.7314	0.9527	0.9384
315	0.2182	3.26	1.5447	0.8499	0.8372
315	0.2727	2.4334	1.1429	0.6288	0.6194
315	0.3272	0.6081	0.2556	0.1406	0.1385
Base		0.0674	−0.0073	−0.004	−0.004
Base		0.0956	0.0064	0.0035	0.0035

Table III. Continued

(c) $\alpha = 0°$

$$\left[\begin{array}{c} p_{t,1} = 126 \text{ psi};\ T_{t,1} = 924.7° \text{R};\ p_{t,2} = 3.8198 \text{ psi};\ M_\infty = 5.967;\ p_\infty = 0.0825 \text{ psi};\ q_\infty = 2.0560 \text{ psi}; \\ T_\infty = 113.9° \text{R};\ \rho_\infty = 6.080 \times 10^{-5} \text{ slugs/ft}^3;\ \ U_\infty = 3121 \text{ fps};\ \text{Re}_{\infty,L} = 662\,129;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	3.8765	1.8449	1.0152	1.0000
0	−0.0545	3.7711	1.7936	0.987	0.9722
0	−0.1091	3.6415	1.7306	0.9523	0.938
0	−0.1636	3.1345	1.4841	0.8166	0.8044
0	−0.2182	2.3858	1.12	0.6163	0.6071
0	−0.2727	0.6611	0.2814	0.1548	0.1525
180	0.0545	3.8036	1.8094	0.9957	0.9808
180	0.1091	3.7114	1.7646	0.971	0.9565
180	0.1636	3.604	1.7124	0.9423	0.9281
180	0.2182	3.4902	1.6575	0.9118	0.8984
180	0.2727	3.4483	1.6367	0.9006	0.8871
180	0.3272	3.4074	1.6168	0.8897	0.8763
180	0.3818	3.3406	1.5843	0.8718	0.8587
180	0.4363	3.3336	1.5813	0.8699	0.8571
180	0.4909	3.2769	1.5533	0.8547	0.8419
180	0.5454	3.2009	1.5164	0.8344	0.8219
180	0.5999	3.1132	1.4737	0.8109	0.7988
180	0.6545	2.9961	1.4168	0.7796	0.7679
180	0.709	2.7621	1.303	0.717	0.7063
180	0.7636	1.6826	0.7781	0.4281	0.4217
180	0.8181	0.3149	0.113	0.0622	0.0613
0/225	0.0000	3.8765	1.8449	1.0152	1.0000
225	0.0545	3.8646	1.8395	1.012	0.9971
225	0.1091	3.6974	1.7578	0.9672	0.9528
225	0.1636	3.6556	1.7375	0.9561	0.9417
225	0.2182	3.5059	1.6647	0.916	0.9023
225	0.2727	3.4705	1.6475	0.9065	0.893
225	0.3272	3.4065	1.6163	0.8894	0.8761
225	0.3818	3.3741	1.6006	0.8807	0.8676
225	0.4363	3.3125	1.5706	0.8643	0.8513
225	0.4909	3.2275	1.5293	0.8415	0.8289
225	0.5454	3.1018	1.4682	0.8079	0.7958
225	0.5999	2.8398	1.3408	0.7378	0.7267
225	0.6545	1.9301	0.8984	0.4944	0.487
225	0.709	0.3556	0.1328	0.0731	0.072
0/250	0.0000	3.8765	1.8449	1.0152	1.0000
250	0.1091	3.7589	1.7877	0.9837	0.969
250	0.1636	3.6883	1.7534	0.9648	0.9504
250	0.2182	3.5318	1.6773	0.9229	0.9091
250	0.2727	3.4406	1.6329	0.8985	0.8851
250	0.3272	3.3381	1.5831	0.8711	0.8581
250	0.3818	3.2786	1.5545	0.8552	0.8426
250	0.4363	3.1776	1.505	0.8282	0.8158
250	0.4909	2.8536	1.3475	0.7415	0.7304
250	0.5454	1.1529	0.5205	0.2864	0.2821
250	0.5999	0.228	0.0708	0.0389	0.0383

Table III. Continued

(c) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	3.8765	1.8449	1.0152	1.0000
270	0.1091	3.775	1.7955	0.988	0.9732
270	0.1636	3.6842	1.7514	0.9637	0.9493
270	0.2182	3.5052	1.6643	0.9158	0.9021
270	0.2727	3.3677	1.5975	0.879	0.8659
270	0.3272	3.2434	1.537	0.8458	0.8331
270	0.3818	2.9671	1.4027	0.7718	0.7603
270	0.4363	1.4714	0.6754	0.3716	0.3661
270	0.4909	0.3123	0.1117	0.0615	0.0606
0/290	0.0000	3.8765	1.8449	1.0152	1.0000
290	0.1091	3.6925	1.7554	0.9659	0.9515
290	0.1636	3.6077	1.7142	0.9432	0.9291
290	0.2182	3.3768	1.6019	0.8815	0.8683
290	0.2727	3.0985	1.4666	0.807	0.7949
290	0.3272	2.594	1.2212	0.672	0.6619
290	0.3818	0.6071	0.2551	0.1404	0.1383
0/315	0.0000	3.8765	1.8449	1.0152	1.0000
315	0.0545	3.8147	1.8148	0.9986	0.9837
315	0.1091	3.6317	1.7263	0.9497	0.9357
315	0.1636	3.4613	1.643	0.9041	0.8905
315	0.2182	3.0395	1.4379	0.7912	0.7794
315	0.2727	2.2043	1.0318	0.5677	0.5592
315	0.3272	0.4754	0.1911	0.1051	0.1036
Base		0.0677	−0.0072	−0.004	−0.0039
Base		0.0957	0.0064	0.0035	0.0035

Table III. Continued

(d) $\alpha = 5°$

$$\left[\begin{array}{c} p_{t,1} = 126.6 \text{ psi};\ T_{t,1} = 931.7°\text{R};\ p_{t,2} = 3.8985 \text{ psi};\ M_\infty = 5.946;\ p_\infty = 0.0848 \text{ psi};\ q_\infty = 2.0990 \text{ psi}; \\ T_\infty = 115.5°\text{R};\ \rho_\infty = 6.164 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3132 \text{ fps};\ \text{Re}_{\infty,L} = 663046;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	3.938	1.8358	1.0104	0.9952
0	−0.0545	3.7348	1.739	0.9571	0.9427
0	−0.1091	3.4805	1.6178	0.8904	0.8771
0	−0.1636	2.9583	1.3691	0.7535	0.7422
0	−0.2182	2.1588	0.9881	0.5438	0.5357
0	−0.2727	0.5273	0.2108	0.116	0.1143
180	0.0545	3.9353	1.8345	1.0096	0.9945
180	0.1091	3.9244	1.8293	1.0068	0.9917
180	0.1636	3.8429	1.7905	0.9854	0.9707
180	0.2182	3.7934	1.7669	0.9725	0.9577
180	0.2727	3.687	1.7162	0.9445	0.9304
180	0.3272	3.6375	1.6926	0.9316	0.9176
180	0.3818	3.6112	1.6801	0.9247	0.9108
180	0.4363	3.5956	1.6726	0.9206	0.9066
180	0.4909	3.4803	1.6178	0.8903	0.877
180	0.5454	3.3989	1.579	0.869	0.856
180	0.5999	3.3004	1.532	0.8432	0.8305
180	0.6545	3.1691	1.4695	0.8087	0.7966
180	0.709	2.91	1.346	0.7408	0.7297
180	0.7636	1.7852	0.8101	0.4459	0.4392
180	0.8181	0.3659	0.1339	0.0737	0.0726
0/225	0.0000	3.938	1.8358	1.0104	0.9952
225	0.0545	3.9557	1.8442	1.015	0.9996
225	0.1091	3.859	1.7982	0.9896	0.9748
225	0.1636	3.8258	1.7824	0.9809	0.9663
225	0.2182	3.7225	1.7331	0.9539	0.9396
225	0.2727	3.6649	1.7057	0.9387	0.9247
225	0.3272	3.5824	1.6664	0.9171	0.9034
225	0.3818	3.5436	1.6479	0.9069	0.8934
225	0.4363	3.4795	1.6174	0.8901	0.8768
225	0.4909	3.3864	1.573	0.8657	0.8528
225	0.5454	3.2518	1.5089	0.8304	0.818
225	0.5999	2.9712	1.3752	0.7569	0.7455
225	0.6545	2.0455	0.9342	0.5141	0.5064
225	0.709	0.3829	0.142	0.0782	0.077
0/250	0.0000	3.938	1.8358	1.0104	0.9952
250	0.1091	3.8663	1.8017	0.9916	0.9767
250	0.1636	3.7774	1.7593	0.9682	0.9537
250	0.2182	3.6433	1.6954	0.9331	0.9191
250	0.2727	3.5452	1.6487	0.9074	0.8938
250	0.3272	3.4789	1.6171	0.89	0.8767
250	0.3818	3.4043	1.5814	0.8704	0.8572
250	0.4363	3.2549	1.5104	0.8312	0.8188
250	0.4909	2.9204	1.351	0.7435	0.7324
250	0.5454	1.1446	0.5049	0.2779	0.2737
250	0.5999	0.2229	0.0658	0.0362	0.0357

Table III. Continued

(d) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	3.938	1.8358	1.0104	0.9952
270	0.1091	3.8278	1.7833	0.9815	0.9668
270	0.1636	3.6888	1.7171	0.945	0.9309
270	0.2182	3.5165	1.635	0.8998	0.8864
270	0.2727	3.3679	1.5642	0.8609	0.848
270	0.3272	3.2329	1.4999	0.8255	0.8131
270	0.3818	2.9438	1.3621	0.7497	0.7384
270	0.4363	1.4194	0.6359	0.3499	0.3447
270	0.4909	0.2673	0.087	0.0479	0.0471
0/290	0.0000	3.938	1.8358	1.0104	0.9952
290	0.1091	3.6831	1.7144	0.9435	0.9294
290	0.1636	3.524	1.6386	0.9018	0.8883
290	0.2182	3.2869	1.5256	0.8396	0.8271
290	0.2727	2.9959	1.387	0.7633	0.7519
290	0.3272	2.4906	1.1462	0.6308	0.6214
290	0.3818	0.5102	0.2027	0.1115	0.1099
0/315	0.0000	3.938	1.8358	1.0104	0.9952
315	0.0545	3.803	1.7715	0.975	0.9604
315	0.1091	3.5208	1.637	0.901	0.8873
315	0.1636	3.2928	1.5284	0.8412	0.8286
315	0.2182	2.8507	1.3178	0.7253	0.7144
315	0.2727	2.0195	0.9218	0.5073	0.4997
315	0.3272	0.3903	0.1456	0.0801	0.0789
Base		0.0731	−0.0056	−0.0031	−0.003
Base		0.1005	0.0075	0.0041	0.0041

Table III. Continued

(e) $\alpha = 10°$

$$\left[\begin{array}{c} p_{t,1} = 124.4 \text{ psi};\ T_{t,1} = 925.7°\text{R};\ p_{t,2} = 3.8027 \text{ psi};\ M_\infty = 5.956;\ p_\infty = 0.0824 \text{ psi};\ q_\infty = 2.0470 \text{ psi}; \\ T_\infty = 114.4°\text{R};\ \rho_\infty = 6.049 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 3122 \text{ fps};\ \text{Re}_{\infty,L} = 655\,706;\ \gamma_\infty = 1.4 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	3.6987	1.7664	0.972	0.9575
0	−0.0545	3.4274	1.6339	0.8991	0.8857
0	−0.1091	3.1557	1.5011	0.8261	0.8137
0	−0.1636	2.585	1.2224	0.6727	0.6626
0	−0.2182	1.8386	0.8578	0.4721	0.465
0	−0.2727	0.4107	0.1604	0.0882	0.0869
180	0.0545	3.7823	1.8072	0.9945	0.9796
180	0.1091	3.8478	1.8392	1.0121	0.997
180	0.1636	3.8763	1.8531	1.0198	1.0045
180	0.2182	3.766	1.7995	0.9901	0.9754
180	0.2727	3.7683	1.8004	0.9908	0.9759
180	0.3272	3.7173	1.7755	0.977	0.9624
180	0.3818	3.6601	1.7475	0.9617	0.9473
180	0.4363	3.5791	1.7082	0.9399	0.9259
180	0.4909	3.5724	1.7047	0.9381	0.9241
180	0.5454	3.4897	1.6643	0.9159	0.9022
180	0.5999	3.3929	1.617	0.8898	0.8765
180	0.6545	3.2577	1.551	0.8535	0.8407
180	0.709	2.9957	1.423	0.7831	0.7714
180	0.7636	1.8995	0.8876	0.4884	0.4811
180	0.8181	0.4469	0.178	0.098	0.0965
0/225	0.0000	3.6987	1.7664	0.972	0.9575
225	0.0545	3.7169	1.7755	0.9769	0.9624
225	0.1091	3.7408	1.7869	0.9834	0.9686
225	0.1636	3.8021	1.8169	0.9998	0.9849
225	0.2182	3.7392	1.7862	0.9829	0.9682
225	0.2727	3.6812	1.7578	0.9673	0.9529
225	0.3272	3.6009	1.7186	0.9458	0.9316
225	0.3818	3.5662	1.7017	0.9364	0.9224
225	0.4363	3.4991	1.6689	0.9184	0.9046
225	0.4909	3.408	1.6244	0.8939	0.8805
225	0.5454	3.2781	1.5609	0.859	0.8461
225	0.5999	3.0036	1.4269	0.7852	0.7734
225	0.6545	2.0936	0.9824	0.5406	0.5325
225	0.709	0.4257	0.1677	0.0923	0.0909
0/250	0.0000	3.6987	1.7664	0.972	0.9575
250	0.1091	3.6834	1.7589	0.9679	0.9534
250	0.1636	3.6619	1.7484	0.9622	0.9477
250	0.2182	3.5617	1.6995	0.9352	0.9212
250	0.2727	3.469	1.6542	0.9103	0.8967
250	0.3272	3.3632	1.6025	0.8819	0.8687
250	0.3818	3.2577	1.5512	0.8535	0.8408
250	0.4363	3.1818	1.5139	0.8331	0.8206
250	0.4909	2.851	1.3523	0.7442	0.733
250	0.5454	1.1053	0.4996	0.275	0.2708
250	0.5999	0.214	0.0643	0.0354	0.0348

Table III. Concluded

(e) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	3.6987	1.7664	0.972	0.9575
270	0.1091	3.5861	1.7114	0.9418	0.9277
270	0.1636	3.4923	1.6656	0.9166	0.9028
270	0.2182	3.329	1.5858	0.8727	0.8596
270	0.2727	3.187	1.5164	0.8345	0.822
270	0.3272	3.0558	1.4524	0.7992	0.7873
270	0.3818	2.7831	1.3192	0.7259	0.7151
270	0.4363	1.2834	0.5866	0.3228	0.318
270	0.4909	0.2328	0.0735	0.0404	0.0398
0/290	0.0000	3.6987	1.7664	0.972	0.9575
290	0.1091	3.3943	1.6177	0.8902	0.8769
290	0.1636	3.2606	1.5524	0.8543	0.8415
290	0.2182	3.0172	1.4335	0.7889	0.777
290	0.2727	2.7524	1.3042	0.7177	0.7069
290	0.3272	2.2766	1.0718	0.5898	0.581
290	0.3818	0.4193	0.1646	0.0906	0.0892
0/315	0.0000	3.6987	1.7664	0.972	0.9575
315	0.0545	3.5105	1.6744	0.9215	0.9077
315	0.1091	3.1746	1.5106	0.8312	0.8188
315	0.1636	2.9793	1.415	0.7787	0.767
315	0.2182	2.5414	1.2011	0.661	0.6511
315	0.2727	1.7518	0.8154	0.4487	0.442
315	0.3272	0.3126	0.1124	0.0619	0.061
Base		0.0724	−0.0049	−0.0027	−0.0026
Base		0.0996	0.0084	0.0046	0.0046

Table IV. Measured Pressure Distribution Data in CF_4 at Mach 6.25 for Low Reservoir Pressure Condition

(a) $\alpha = -10°$

$$\left[\begin{array}{c} p_{t,1} = 2140 \text{ psi; } T_{t,1} = 1165°\text{R; } p_{t,2} = 2.6507 \text{ psi; } M_\infty = 6.307\text{; } p_\infty = 0.0550 \text{ psi; } q_\infty = 1.3540 \text{ psi;} \\ T_\infty = 292.3°\text{R; } \rho_\infty = 4.789 \times 10^{-5} \text{ slugs/ft}^3\text{; } U_\infty = 2852 \text{ fps; } \text{Re}_{\infty,L} = 201\,146\text{; } \gamma_\infty = 1.2 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	2.5578	1.8483	0.9642	0.9642
0	−0.0545	2.6337	1.9044	0.9935	0.9935
0	−0.1091	2.6374	1.9071	0.9949	0.9949
0	−0.1636	2.5194	1.8200	0.9494	0.9494
0	−0.2182	2.0912	1.5038	0.7845	0.7845
0	−0.2727	0.8200	0.5650	0.2947	0.2947
180	0.0545	2.4193	1.7461	0.9109	0.9109
180	0.1091	2.1924	1.5785	0.8234	0.8234
180	0.1636	1.8824	1.3496	0.7040	0.7040
180	0.2182	1.5395	1.0964	0.5719	0.5717
180	0.2727	1.5449	1.1003	0.5740	0.5740
180	0.3272	1.6319	1.1646	0.6075	0.6075
180	0.3818	1.6866	1.2050	0.6286	0.6286
180	0.4363	1.7374	1.2425	0.6481	0.6479
180	0.4909	1.7079	1.2207	0.6368	0.6368
180	0.5454	1.7107	1.2228	0.6379	0.6379
180	0.5999	1.7159	1.2266	0.6399	0.6399
180	0.6545	1.7088	1.2214	0.6371	0.6371
180	0.7090	1.6670	1.1905	0.6210	0.6210
180	0.7636	1.1525	0.8105	0.4228	0.4228
180	0.8181	0.2361	0.1338	0.0698	0.0698
0/225	0.0000	2.5578	1.8483	0.9642	0.9642
225	0.0545	2.5216	1.8217	0.9503	0.9499
225	0.1091	2.3246	1.6761	0.8744	0.8744
225	0.1636	2.0999	1.5102	0.7878	0.7878
225	0.2182	1.7387	1.2434	0.6487	0.6487
225	0.2727	1.7111	1.2230	0.6380	0.6380
225	0.3272	1.7733	1.2690	0.6620	0.6620
225	0.3818	1.8114	1.2971	0.6767	0.6767
225	0.4363	1.8285	1.3097	0.6832	0.6832
225	0.4909	1.8399	1.3182	0.6876	0.6876
225	0.5454	1.8332	1.3132	0.6851	0.6851
225	0.5999	1.7827	1.2759	0.6656	0.6656
225	0.6545	1.2919	0.9135	0.4765	0.4765
225	0.7090	0.2582	0.1501	0.0783	0.0783
0/250	0.0000	2.5578	1.8483	0.9642	0.9642
250	0.1636	2.3139	1.6682	0.8702	0.8702
250	0.2182	2.0545	1.4766	0.7703	0.7703
250	0.2727	1.9498	1.3993	0.7300	0.7300
250	0.3272	1.9923	1.4307	0.7464	0.7464
250	0.3818	2.0059	1.4408	0.7516	0.7513
250	0.4363	1.9964	1.4337	0.7479	0.7479
250	0.4909	1.9000	1.3626	0.7108	0.7108
250	0.5454	0.9137	0.6342	0.3308	0.3308
250	0.5999	0.2032	0.1095	0.0571	0.0571

Table IV. Continued

(a) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	2.5578	1.8483	0.9642	0.9642
270	0.1091	2.5389	1.8344	0.9569	0.9569
270	0.1636	2.4505	1.7691	0.9229	0.9229
270	0.2182	2.2745	1.6391	0.8551	0.8551
270	0.2727	2.1727	1.5639	0.8159	0.8159
270	0.3272	2.1668	1.5596	0.8136	0.8136
270	0.3818	2.0829	1.4976	0.7813	0.7813
270	0.4363	1.2565	0.8873	0.4629	0.4629
270	0.4909	0.3537	0.2206	0.1151	0.1151
0/290	0.0000	2.5578	1.8483	0.9642	0.9642
290	0.1091	2.6092	1.8863	0.9840	0.9840
290	0.1636	2.5557	1.8468	0.9634	0.9634
290	0.2182	2.3994	1.7314	0.9032	0.9032
290	0.2727	2.2736	1.6385	0.8547	0.8547
290	0.3272	2.0209	1.4518	0.7574	0.7574
290	0.3818	0.6872	0.4669	0.2436	0.2436
0/315	0.0000	2.5578	1.8483	0.9642	0.9642
315	0.0545	2.6254	1.8983	0.9903	0.9903
315	0.1091	2.6417	1.9103	0.9965	0.9965
315	0.1636	2.5957	1.8763	0.9788	0.9788
315	0.2182	2.4245	1.7499	0.9129	0.9129
315	0.2727	1.9436	1.3948	0.7276	0.7276
315	0.3272	0.5777	0.3860	0.2014	0.2014
Base	0.0000	0.0431	−0.0088	−0.0046	−0.0046
Base	0.0000	0.0468	−0.0060	−0.0031	−0.0031

Table IV. Continued

(b) $\alpha = -5°$

$$\left[\begin{array}{c} p_{t,1} = 2104 \text{ psi};\ T_{t,1} = 1231°\text{R};\ p_{t,2} = 2.5596 \text{ psi};\ M_\infty = 6.205;\ p_\infty = 0.0555 \text{ psi};\ q_\infty = 1.3050 \text{ psi}; \\ T_\infty = 329.0°\text{R};\ \rho_\infty = 4.298 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 2956 \text{ fps};\ \text{Re}_{\infty,L} = 166648;\ \gamma_\infty = 1.2 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	2.5614	1.9195	1.0007	1.0007
0	−0.0545	2.5860	1.9383	1.0105	1.0105
0	−0.1091	2.5333	1.8980	0.9895	0.9895
0	−0.1636	2.3668	1.7704	0.9230	0.9230
0	−0.2182	1.8866	1.4026	0.7312	0.7312
0	−0.2727	0.6573	0.4610	0.2403	0.2403
180	0.0545	2.4707	1.8500	0.9645	0.9645
180	0.1091	2.2942	1.7148	0.8940	0.8940
180	0.1636	2.0276	1.5106	0.7875	0.7875
180	0.2182	1.7589	1.3053	0.6802	0.6806
180	0.2727	1.8112	1.3448	0.7011	0.7011
180	0.3272	1.8552	1.3785	0.7187	0.7187
180	0.3818	1.8767	1.3950	0.7273	0.7273
180	0.4363	1.8968	1.4109	0.7353	0.7357
180	0.4909	1.8996	1.4125	0.7364	0.7364
180	0.5454	1.9035	1.4155	0.7380	0.7380
180	0.5999	1.9038	1.4158	0.7381	0.7381
180	0.6545	1.8968	1.4104	0.7353	0.7353
180	0.7090	1.8453	1.3710	0.7147	0.7147
180	0.7636	1.2899	0.9455	0.4929	0.4929
180	0.8181	0.2722	0.1660	0.0865	0.0865
0/225	0.0000	2.5614	1.9195	1.0007	1.0007
225	0.0545	2.4964	1.8704	0.9748	0.9753
225	0.1091	2.3986	1.7948	0.9357	0.9357
225	0.1636	2.2003	1.6429	0.8565	0.8565
225	0.2182	1.9111	1.4214	0.7410	0.7410
225	0.2727	1.9287	1.4348	0.7481	0.7481
225	0.3272	1.9717	1.4678	0.7652	0.7652
225	0.3818	1.9947	1.4854	0.7744	0.7744
225	0.4363	1.9993	1.4889	0.7762	0.7762
225	0.4909	2.0027	1.4915	0.7776	0.7776
225	0.5454	1.9900	1.4818	0.7725	0.7725
225	0.5999	1.9244	1.4315	0.7463	0.7463
225	0.6545	1.4120	1.0390	0.5417	0.5417
225	0.7090	0.2970	0.1850	0.0964	0.0964
0/250	0.0000	2.5614	1.9195	1.0007	1.0007
250	0.1636	2.3579	1.7636	0.9195	0.9195
250	0.2182	2.1582	1.6106	0.8397	0.8397
250	0.2727	2.0835	1.5534	0.8099	0.8099
250	0.3272	2.1100	1.5737	0.8205	0.8205
250	0.3818	2.097	1.5643	0.8153	0.8157
250	0.4363	2.0962	1.5631	0.8149	0.8149
250	0.4909	1.9877	1.4800	0.7716	0.7716
250	0.5454	0.9380	0.6760	0.3524	0.3524
250	0.5999	0.2131	0.1207	0.0629	0.0629

Table IV. Continued

(b) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\mathrm{max}}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	2.5614	1.9195	1.0007	1.0007
270	0.1091	2.5291	1.8947	0.9878	0.9878
270	0.1636	2.4409	1.8272	0.9526	0.9526
270	0.2182	2.3041	1.7224	0.8980	0.8980
270	0.2727	2.2100	1.6503	0.8604	0.8604
270	0.3272	2.1900	1.6350	0.8524	0.8524
270	0.3818	2.0959	1.5629	0.8148	0.8148
270	0.4363	1.2196	0.8917	0.4649	0.4649
270	0.4909	0.3208	0.2032	0.1059	0.1059
0/290	0.0000	2.5614	1.9195	1.0007	1.0007
290	0.1091	2.5575	1.9165	0.9992	0.9992
290	0.1636	2.4800	1.8571	0.9682	0.9682
290	0.2182	2.3433	1.7524	0.9136	0.9136
290	0.2727	2.2197	1.6577	0.8643	0.8643
290	0.3272	1.9455	1.4477	0.7548	0.7548
290	0.3818	0.5864	0.4066	0.2120	0.2120
0/315	0.0000	2.5614	1.9195	1.0007	1.0007
315	0.0545	2.5916	1.9426	1.0128	1.0128
315	0.1091	2.5656	1.9227	1.0024	1.0024
315	0.1636	2.4607	1.8423	0.9605	0.9605
315	0.2182	2.2545	1.6844	0.8782	0.8782
315	0.2727	1.7759	1.3178	0.6870	0.6870
315	0.3272	0.4796	0.3248	0.1694	0.1694
Base		0.0580	0.0019	0.0010	0.0010
Base		0.0587	0.0024	0.0013	0.0013

Table IV. Continued

(c) $\alpha = 0°$

$$\left[\begin{array}{c} p_{t,1} = 2081 \text{ psi; } T_{t,1} = 1178°\text{R; } p_{t,2} = 2.5660 \text{ psi; } M_\infty = 6.285\text{; } p_\infty = 0.0537 \text{ psi; } q_\infty = 1.3100 \text{ psi;} \\ T_\infty = 299.5°\text{R; } \rho_\infty = 4.568 \times 10^{-5} \text{ slugs/ft}^3\text{; } U_\infty = 2873 \text{ fps; } \text{Re}_{\infty,L} = 188\,637\text{; } \gamma_\infty = 1.2 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0	0.0000	2.567	1.9178	1.0004	1.0004
0	−0.0545	2.5386	1.8961	0.9891	0.9891
0	−0.1091	2.4357	1.8176	0.9481	0.9481
0	−0.1636	2.2042	1.641	0.856	0.856
0	−0.2182	1.7001	1.2563	0.6553	0.6553
0	−0.2727	0.5298	0.3633	0.1895	0.1895
180	0.0545	2.5289	1.8887	0.9852	0.9852
180	0.1091	2.4079	1.7964	0.9371	0.9371
180	0.1636	2.1976	1.6359	0.8534	0.8534
180	0.2182	2.0332	1.511	0.7879	0.7879
180	0.2727	2.0415	1.5168	0.7912	0.7912
180	0.3272	2.067	1.5363	0.8014	0.8014
180	0.3818	2.0813	1.5472	0.8071	0.8071
180	0.4363	2.1231	1.5797	0.8237	0.8237
180	0.4909	2.1025	1.5634	0.8155	0.8155
180	0.5454	2.1048	1.5651	0.8164	0.8164
180	0.5999	2.1017	1.5627	0.8152	0.8152
180	0.6545	2.0863	1.551	0.8091	0.8091
180	0.709	2.0231	1.5028	0.7839	0.7839
180	0.7636	1.4161	1.0396	0.5423	0.5423
180	0.8181	0.3174	0.2012	0.105	0.105
0/225	0.0000	2.567	1.9178	1.0004	1.0004
225	0.0545	2.5555	1.9097	0.9958	0.9958
225	0.1091	2.4769	1.8491	0.9645	0.9645
225	0.1636	2.3292	1.7363	0.9057	0.9057
225	0.2182	2.1144	1.5724	0.8202	0.8202
225	0.2727	2.1207	1.5772	0.8228	0.8228
225	0.3272	2.1486	1.5985	0.8339	0.8339
225	0.3818	2.1735	1.6175	0.8438	0.8438
225	0.4363	2.1756	1.6191	0.8446	0.8446
225	0.4909	2.1778	1.6208	0.8455	0.8455
225	0.5454	2.1594	1.6068	0.8382	0.8382
225	0.5999	2.0896	1.5535	0.8104	0.8104
225	0.6545	1.5414	1.1352	0.5922	0.5922
225	0.709	0.3302	0.211	0.1101	0.1101
0/250	0.0000	2.567	1.9178	1.0004	1.0004
250	0.1636	2.4343	1.8165	0.9476	0.9476
250	0.2182	2.2436	1.671	0.8717	0.8717
250	0.2727	2.1815	1.6236	0.847	0.847
250	0.3272	2.2171	1.6508	0.8611	0.8611
250	0.3818	2.2211	1.6545	0.8627	0.8627
250	0.4363	2.2177	1.6513	0.8614	0.8614
250	0.4909	2.1042	1.5647	0.8162	0.8162
250	0.5454	0.9816	0.708	0.3693	0.3693
250	0.5999	0.2137	0.1221	0.0637	0.0637

Table IV. Continued

(c) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	2.567	1.9178	1.0004	1.0004
270	0.1091	2.5436	1.8999	0.9911	0.9911
270	0.1636	2.457	1.8339	0.9566	0.9566
270	0.2182	2.2951	1.7103	0.8922	0.8922
270	0.2727	2.2097	1.6452	0.8582	0.8582
270	0.3272	2.2096	1.6451	0.8581	0.8581
270	0.3818	2.1225	1.5786	0.8235	0.8235
270	0.4363	1.2042	0.8779	0.4579	0.4579
270	0.4909	0.2832	0.1751	0.0913	0.0913
0/290	0.0000	2.567	1.9178	1.0004	1.0004
290	0.1091	2.5406	1.8977	0.9899	0.9899
290	0.1636	2.4487	1.8275	0.9533	0.9533
290	0.2182	2.2539	1.6789	0.8758	0.8758
290	0.2727	2.1281	1.5829	0.8257	0.8257
290	0.3272	1.8631	1.3807	0.7202	0.7202
290	0.3818	0.5094	0.3477	0.1814	0.1814
0/315	0.0000	2.567	1.9178	1.0004	1.0004
315	0.0545	2.562	1.914	0.9984	0.9984
315	0.1091	2.5093	1.8738	0.9774	0.9774
315	0.1636	2.3681	1.766	0.9212	0.9212
315	0.2182	2.1243	1.58	0.8242	0.8242
315	0.2727	1.6083	1.1863	0.6188	0.6188
315	0.3272	0.38	0.249	0.1299	0.1299
Base		0.0536	−0.0001	0.0000	0.0000
Base		0.0541	0.0003	0.0002	0.0002

Table IV. Continued

(d) $\alpha = 5°$

$$\left[\begin{array}{c} p_{t,1} = 1975 \text{ psi};\ T_{t,1} = 1211°\text{R};\ p_{t,2} = 2.4050 \text{ psi};\ M_\infty = 6.234;\ p_\infty = 0.0515 \text{ psi};\ q_\infty = 1.2270 \text{ psi}; \\ T_\infty = 318.1°\text{R};\ \rho_\infty = 4.124 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 2926 \text{ fps};\ \text{Re}_{\infty,L} = 163\,498;\ \gamma_\infty = 1.2 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	2.4102	1.9223	1.0022	1.0022
0	−0.0545	2.3365	1.8622	0.9709	0.9709
0	−0.1091	2.1871	1.7405	0.9074	0.9074
0	−0.1636	1.8706	1.4825	0.7729	0.7729
0	−0.2182	1.4277	1.1216	0.5847	0.5847
0	−0.2727	0.4006	0.2845	0.1483	0.1483
180	0.0545	2.4160	1.9270	1.0047	1.0047
180	0.1091	2.3538	1.8763	0.9782	0.9782
180	0.1636	2.2276	1.7735	0.9246	0.9246
180	0.2182	2.1378	1.7003	0.8865	0.8866
180	0.2727	2.1278	1.6922	0.8822	0.8822
180	0.3272	2.1449	1.7061	0.8895	0.8895
180	0.3818	2.1525	1.7123	0.8927	0.8927
180	0.4363	2.1851	1.7389	0.9066	0.9067
180	0.4909	2.1611	1.7193	0.8964	0.8964
180	0.5454	2.1535	1.7131	0.8931	0.8931
180	0.5999	2.1423	1.7040	0.8884	0.8884
180	0.6545	2.1196	1.6855	0.8787	0.8787
180	0.7090	2.0475	1.6267	0.8481	0.8481
180	0.7636	1.4265	1.1206	0.5842	0.5842
180	0.8181	0.3193	0.2182	0.1138	0.1138
0/225	0.0000	2.4102	1.9223	1.0022	1.0022
225	0.0545	2.4343	1.942	1.0124	1.0126
225	0.1091	2.3904	1.9062	0.9938	0.9938
225	0.1636	2.2961	1.8293	0.9537	0.9537
225	0.2182	2.1616	1.7197	0.8966	0.8966
225	0.2727	2.1713	1.7276	0.9007	0.9007
225	0.3272	2.1977	1.7491	0.9119	0.9119
225	0.3818	2.2108	1.7598	0.9175	0.9175
225	0.4363	2.2090	1.7583	0.9167	0.9167
225	0.4909	2.1981	1.7495	0.9121	0.9121
225	0.5454	2.1666	1.7238	0.8987	0.8987
225	0.5999	2.0799	1.6531	0.8619	0.8619
225	0.6545	1.5177	1.1949	0.6230	0.6230
225	0.7090	0.3273	0.2248	0.1172	0.1172
0/250	0.0000	2.4102	1.9223	1.0022	1.0022
250	0.1636	2.3314	1.8581	0.9687	0.9687
250	0.2182	2.2010	1.7518	0.9133	0.9133
250	0.2727	2.1551	1.7144	0.8938	0.8938
250	0.3272	2.1716	1.7279	0.9008	0.9008
250	0.3818	2.1752	1.7308	0.9024	0.9025
250	0.4363	2.1622	1.7202	0.8968	0.8968
250	0.4909	2.0470	1.6263	0.8479	0.8479
250	0.5454	0.9312	0.7169	0.3738	0.3738
250	0.5999	0.1969	0.1185	0.0618	0.0618

Table IV. Continued

(d) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	2.4102	1.9223	1.0022	1.0022
270	0.1091	2.3739	1.8927	0.9868	0.9868
270	0.1636	2.3020	1.8341	0.9562	0.9562
270	0.2182	2.1644	1.7220	0.8978	0.8978
270	0.2727	2.0830	1.6556	0.8632	0.8632
270	0.3272	2.0809	1.6539	0.8623	0.8623
270	0.3818	1.9962	1.5849	0.8263	0.8263
270	0.4363	1.1019	0.8561	0.4463	0.4463
270	0.4909	0.2412	0.1546	0.0806	0.0806
0/290	0.0000	2.4102	1.9223	1.0022	1.0022
290	0.1091	2.3414	1.8662	0.9730	0.9730
290	0.1636	2.2387	1.7825	0.9293	0.9293
290	0.2182	2.0516	1.6301	0.8498	0.8498
290	0.2727	1.9271	1.5286	0.7969	0.7969
290	0.3272	1.6768	1.3246	0.6906	0.6906
290	0.3818	0.4139	0.2953	0.1540	0.1540
0/315	0.0000	2.4102	1.9223	1.0022	1.0022
315	0.0545	2.3701	1.8896	0.9852	0.9852
315	0.1091	2.2839	1.8194	0.9485	0.9485
315	0.1636	2.1146	1.6814	0.8766	0.8766
315	0.2182	1.8574	1.4718	0.7673	0.7673
315	0.2727	1.3684	1.0733	0.5595	0.5595
315	0.3272	0.2871	0.1920	0.1001	0.1001
Base		0.0503	−0.0010	−0.0005	−0.0005
Base		0.0527	0.0010	0.0005	0.0005

Table IV. Concluded

(e) $\alpha = 10^\circ$

$$\left[\begin{array}{c} p_{t,1} = 2113 \text{ psi};\ T_{t,1} = 1208^\circ\text{R};\ p_{t,2} = 2.5803 \text{ psi};\ M_\infty = 6.243;\ p_\infty = 0.0551 \text{ psi};\ q_\infty = 1.3170 \text{ psi}; \\ T_\infty = 315.7^\circ\text{R};\ \rho_\infty = 4.444 \times 10^{-5} \text{ slugs/ft}^3;\ U_\infty = 2920 \text{ fps};\ \text{Re}_{\infty,L} = 177\,108;\ \gamma_\infty = 1.2 \end{array}\right]$$

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\text{ref}}$
0	0.0000	2.5355	1.8838	0.9823	0.9823
0	−0.0545	2.4056	1.7852	0.9308	0.9308
0	−0.1091	2.1987	1.628	0.8489	0.8489
0	−0.1636	1.892	1.3951	0.7274	0.7274
0	−0.2182	1.3471	0.9813	0.5117	0.5117
0	−0.2727	0.3525	0.2259	0.1178	0.1178
180	0.0545	2.5901	1.9253	1.0039	1.0039
180	0.1091	2.5886	1.9242	1.0033	1.0033
180	0.1636	2.5459	1.8917	0.9864	0.9864
180	0.2182	2.4806	1.8417	0.9605	0.9603
180	0.2727	2.4697	1.8339	0.9562	0.9562
180	0.3272	2.4642	1.8297	0.954	0.954
180	0.3818	2.4497	1.8187	0.9483	0.9483
180	0.4363	2.4452	1.8148	0.9465	0.9463
180	0.4909	2.4265	1.801	0.9391	0.9391
180	0.5454	2.4025	1.7828	0.9296	0.9296
180	0.5999	2.3719	1.7596	0.9175	0.9175
180	0.6545	2.3153	1.7166	0.8951	0.8951
180	0.709	2.1922	1.6231	0.8463	0.8463
180	0.7636	1.5042	1.1006	0.5739	0.5739
180	0.8181	0.41	0.2696	0.1406	0.1406
0/225	0.0000	2.5355	1.8838	0.9823	0.9823
225	0.0545	2.5748	1.9132	0.9978	0.9976
225	0.1091	2.5912	1.9261	1.0043	1.0043
225	0.1636	2.5564	1.8997	0.9905	0.9905
225	0.2182	2.4848	1.8453	0.9622	0.9622
225	0.2727	2.4772	1.8396	0.9592	0.9592
225	0.3272	2.4764	1.8389	0.9589	0.9589
225	0.3818	2.4762	1.8388	0.9588	0.9588
225	0.4363	2.455	1.8227	0.9504	0.9504
225	0.4909	2.4249	1.7998	0.9385	0.9385
225	0.5454	2.3732	1.7606	0.918	0.918
225	0.5999	2.2484	1.6658	0.8686	0.8686
225	0.6545	1.6296	1.1958	0.6235	0.6235
225	0.709	0.4029	0.2642	0.1377	0.1377
0/250	0.0000	2.5355	1.8838	0.9823	0.9823
250	0.1636	2.5243	1.8753	0.9778	0.9778
250	0.2182	2.4182	1.7947	0.9358	0.9358
250	0.2727	2.3708	1.7587	0.917	0.917
250	0.3272	2.3708	1.7587	0.917	0.917
250	0.3818	2.3275	1.7254	0.8999	0.8997
250	0.4363	2.3299	1.7277	0.9008	0.9008
250	0.4909	2.1781	1.6124	0.8407	0.8407
250	0.5454	0.9789	0.7016	0.3658	0.3658
250	0.5999	0.2249	0.129	0.0673	0.0673

Table IV. Concluded

(e) Concluded

Φ, deg	s/L	p, psi	C_p	$C_p/C_{p,\max}$	$C_p/C_{p,\mathrm{ref}}$
0/270	0.0000	2.5355	1.8838	0.9823	0.9823
270	0.1091	2.5059	1.8613	0.9705	0.9705
270	0.1636	2.4217	1.7974	0.9372	0.9372
270	0.2182	2.278	1.6883	0.8803	0.8803
270	0.2727	2.1972	1.6269	0.8483	0.8483
270	0.3272	2.1877	1.6197	0.8445	0.8445
270	0.3818	2.0928	1.5476	0.8069	0.8069
270	0.4363	1.1295	0.816	0.4255	0.4255
270	0.4909	0.2547	0.1516	0.0791	0.0791
0/290	0.0000	2.5355	1.8838	0.9823	0.9823
290	0.1091	2.4333	1.8062	0.9418	0.9418
290	0.1636	2.292	1.6989	0.8858	0.8858
290	0.2182	2.0688	1.5294	0.7974	0.7974
290	0.2727	1.9457	1.4359	0.7487	0.7487
290	0.3272	1.699	1.2485	0.651	0.651
290	0.3818	0.4022	0.2636	0.1375	0.1375
0/315	0.0000	2.5355	1.8838	0.9823	0.9823
315	0.0545	2.4569	1.8241	0.9511	0.9511
315	0.1091	2.3283	1.7265	0.9002	0.9002
315	0.1636	2.1189	1.5674	0.8173	0.8173
315	0.2182	1.7998	1.3251	0.6909	0.6909
315	0.2727	1.3035	0.9482	0.4944	0.4944
315	0.3272	0.2622	0.1573	0.082	0.082
Base		0.0714	0.0124	0.0065	0.0065
Base		0.0693	0.0108	0.0056	0.0056

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13. ABSTRACT *(Maximum 200 words)*

Pressure distributions measured on a 60° half-angle elliptic cone, raked off at an angle of 73° from the cone centerline and having an ellipsoid nose (ellipticity equal to 2.0 in the symmetry plane), are presented for angles of attack from −10° to 10°. The high normal shock density ratio aspect of a real gas was simulated by testing in Mach 6 air and CF_4 (density ratio equal to 5.25 and 12.0, respectively). The effects of Reynolds number, angle of attack, and normal shock density ratio on these measurements are examined, and comparisons with a three-dimensional Euler code known as HALIS are made. A significant effect of density ratio on pressure distributions on the cone section of the configuration was observed; the magnitude of this effect decreased with increasing angle of attack. The effect of Reynolds number on pressure distributions was negligible for forebody pressure distributions, but a measurable effect was noted on base pressures. In general, the HALIS code accurately predicted the measured pressure distributions in air and CF_4.

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